6 PROPERTY REQUIREMENTS

6.1 GENERAL

6.1.1 Scope

1 This Part includes Grades 15 MPa and above of concrete to be used in the civil works, with the requirements for workability, permeability, and drying shrinkage.

2 Related Sections and Parts are as follows:

This Section
Part 2, ...Aggregates
Part 3, ...Cementitious Materials
Part 4, ...Water
Part 5, ...Admixtures
Part 7, ...Concrete Plants
Part 8, ...Transportation and Placing of Concrete
Part 9, ...Formwork
Part 13, ...Inspection and Testing of Hardened Concrete

6.1.2 References

1 The following standards are referred to in this Part. The designer along with contractor are responsible to use the latest update standard as published by the organization:

ACI 207.1R..... Guide to Mass Concrete
ACI 207.2R..... Report on Thermal and Volume Change Effects on Cracking of Mass Concrete
ACI 207.5R..... Roller - Compacted mass concrete
ACI 213, ... Guide for Structural Lightweight-Aggregate Concrete
ACI 214, ... Evaluation of Strength Test Results of Concrete
ACI 221, ... Guide for Use of Normal Weight and Heavyweight Aggregates in Concrete
ACI 237R 07 ..... Self Consolidating Concrete
ACI 301, ... Specifications for Structural Concrete
ACI 304, ... Guide for Measuring, Mixing, Transporting, and Placing Concrete
ACI 304.2, ... Placing Concrete by Pumping Methods
ACI 318, ... Metric Building Code Requirements for Structural Concrete & Commentary
ACI 506, ... Guide to Shotcrete
ACI 506.1, ... Guide to Fiber-Reinforced Shotcrete
ACI 506.2, ... Specification for Shotcrete
ACI 555, ... Removal and Reuse of Hardened Concrete

ASTM A 820,..... Specification for Steel Fibers for Fiber-Reinforced Concrete

ASTM C 31,..... Practice for making and curing concrete test specimens in the field

ASTM C 33, ... Specification for Concrete Aggregates

ASTM C 39,..... Test Method for Compressive Strength of Cylindrical Concrete Specimens

ASTM C 42,..... Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete

ASTM C 94,..... Specification for Ready-Mixed Concrete

ASTM C192,..... Practice for Making and Curing Concrete Test Specimens in the Laboratory

ASTM E 119,..... Test Methods for Fire Tests of Building Construction and Materials

ASTM C 138,..... Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete

ASTM C 150, ... Specification for Portland Cement

ASTM C 172,..... Practice for Sampling Freshly Mixed Concrete

ASTM C 173,..... Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method

ASTM C 231..... Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method

ASTM C 232, ... Test Methods for Bleeding of Concrete

ASTM C 311, ... Test Methods for Sampling and Testing Fly Ash or Natural Pozzolans for Use in Portland-Cement Concrete

ASTM C 387,..... Specification for Packaged, Dry, Combined Materials for Mortar and Concrete

ASTM C 597,..... Test Method for Pulse Velocity through Concrete

ASTM C 617, ... Practice for Capping Cylindrical Concrete Specimens

ASTM C 618, ... Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete

ASTM C 637,..... Specification for Aggregates for Radiation-Shielding Concrete

ASTM C 638, ... Descriptive Nonmenclature of Constituents of Aggregates for Radiation-Shielding Concrete

ASTM C 803, ... Test Method for Penetration Resistance of Hardened Concrete

ASTM C 805, ... Test Method for Rebound Number of Hardened Concrete

ASTM C 856, ... Practice for Petrographic Examination of Hardened Concrete

ASTM C 900, ... Test Method for Pullout Strength of Hardened Concrete

ASTM C 989,..... Standard Specification for Slag Cement for Use in Concrete and Mortars

ASTM C 1018,..... Test Method for Flexural Toughness and First-Crack Strength of Fiber-Reinforced Concrete

ASTM C 1116, ... Specification for Fiber-Reinforced Concrete

ASTM C 1140,..... Practice for Preparing and Testing Specimens from Shotcrete Test Panels

ASTM C 1152..... Standard Test Method for Acid-Soluble Chloride in Morter and Concrete.

ASTM C 1218..... Standard Test Method for Water-Soluble Chloride in Morter and Concrete.

ASTM C 1231,..... Practice for Use of Unbonded Caps in Determination of Compressive Strength of Hardened Concrete Cylinders

ASTM C 1240,..... Specification for Silica Fume Used in Cementitious Mixtures

ASTM C 1385,..... Practice for Sampling Materials for Shotcrete

ASTM C 1399,..... Test Method for Obtaining Average Residual-Strength of Fiber-Reinforced Concrete

ASTM C 1480,..... Specification for Packaged, Pre-Blended, Dry, Combined Materials for Use in Wet or Dry Shotcrete Application

ASTM C 1550,..... Test Method for Flexural Toughness of Fiber Reinforced Concrete (Using Centrally Loaded Round Panel)

ASTM C 1604,..... Test Method for Obtaining and Testing Drilled Cores of Shotcrete

ASTM C 1609,..... Test Method for Flexural Performance of Fiber-Reinforced Concrete (Using Beam With Third-Point Loading)

ASTM C 1611,..... Test Method for Slump Flow of Self-Compacting Concrete

ASTM C 1666,..... Specification for Alkali Resistant (AR) Glass Fiber for GFRC and Fiber-Reinforced Concrete and Cement

ASTM D 5759,..... Guide for Characterization of Coal Fly Ash and Clean Coal Combustion Fly Ash for Potential Uses

ASTM D 6942,..... Test Method for Stability of Cellulose Fibers in Alkaline Environments

BRE digest 433, ... Recycled Aggregates

BS 4027, ... Specification for Sulphate-Resisting Portland Cement

BS 6073-2, ... Precast concrete masonry units. Guide for specifying precast concrete masonry units

BS 8500, ... Concrete. Complementary British Standard to BS EN 206.

BS 8666, ... Specification for scheduling, dimensioning, bending and cutting of steel reinforcement for concrete

EN 206, ... Concrete. Specification, Performance, Production And Conformity

EN 450, ... Fly Ash for Concrete. Definition, Specifications And Conformity Criteria

EN 771-3, ... Specification for masonry units. Aggregate concrete masonry units (dense and light-weight aggregates

EN 772-2, ... Methods of test for masonry units. Determination of percentage area of voids in masonry units (by paper indentation)

EN 12350, ... Testing Fresh Concrete

EN 12350-1, ... Testing fresh concrete - Part 1: Sampling

EN 12350-2, ... Testing fresh concrete - Part 2: Slump test

EN 12350-3, ... Testing fresh concrete - Part 3: Vebe test

EN 12350-4, ... Testing fresh concrete - Part 4: Degree of compactability

EN 12350-5, ... Testing fresh concrete - Part 5: Flow table test

EN 12350-6, ... Testing fresh concrete - Part 6: Density

EN 12350-7, ... Testing fresh concrete - Part 7: Air content - Pressure methods

EN 12390, ... Testing Hardened Concrete

EN 12390-1, ... Testing hardened concrete - Part 1: Shape, dimensions and other requirements for specimens and moulds

EN 12390-2, ... Testing hardened concrete - Part 2: Making and curing specimens for strength tests

EN 12390-3, ... Testing hardened concrete - Part 3: Compressive strength of test specimens

EN 12390-4, ... Testing hardened concrete - Part 4: Compressive strength - Specification for testing machines

EN 12390-5, ... Testing hardened concrete - Part 5: Flexural strength of test specimens

EN 12390-6, ... Testing hardened concrete - Part 6: Tensile splitting strength of test specimens

EN 12390-7, ... Testing hardened concrete - Part 7: Density of hardened concrete

EN 12390-8, ... Testing hardened concrete - Part 8: Depth of penetration of water under pressure

EN 12620, ... Aggregate For Concrete

EN 15167 ..... Ground Granulated Blast Furnace Slag For Use In Concrete, Mortar And Grout. Conformity Evaluation

EN 1744, ... Tests For Chemical Properties Of Aggregates

EN 1992-3 ..... Eurocode 2. Design of concrete structures. Liquid retaining and containing structures

BS EN 1992-3 ..... UK National Annex to Eurocode 2. Design of concrete structures. Liquid retaining and containment structures

BS PD 6682-1, ... Aggregates for Concrete. Guidance on the Use of BS EN 12620

Concrete Society Report No. 31, Permeability testing of site concrete

CSTR11 ..... Concrete core testing for strength– The Concrete Society Technical Report 11

EN 1011, ... Welding. Recommendation for welding of metallic materials

EN 1992-1-1,..... Eurocode 2: Design of concrete structures. General rules and rules for buildings

ISO 1920-1..... Testing of concrete —Part 1: Sampling of fresh concrete

ISO 1920-2..... Testing of concrete – part 2: properties of fresh concrete

ISO 1920-3..... Testing of concrete – part 3: Making and curing test specimens.

ISO 1920-4 ..... Testing of concrete – part 4: strength of hardened concrete.

ISO 1920-5 ..... Testing of concrete – part 5: properties hardened concrete other than strength.

ISO 1920-6..... Testing of concrete – part 6: sampling, preparing and testing of concrete core .

ISO 1920-7 ..... Testing of concrete – part 7: Non –destructive test on hardened concrete.

ISO 1920-8..... Testing of concrete -- Part 8: Determination of drying shrinkage of concrete for samples prepared in the field or in the laboratory

ISO 1920-9..... Testing of concrete -- Part 9: Determination of creep of concrete cylinders in compression

ISO 1920-10..... Testing of concrete -- Part 10: Determination of static modulus of elasticity in compression

RILEM CPC 11.3 ... Absorption of water by immersion under vacuum

The Concrete Society CS163. Guide to the design of concrete structures in the Arabian Peninsula.

The European Guidelines for Self-Compacting Concrete Specification, Production and Use

6.1.3 Definitions:

1 Exposure conditions will apply as follows:

(a) Class X0: No risk of corrosion or attack. Non saline conditions. Blinding concrete, non-reinforced concrete or slab on ground.

(b) Class X1: Mild exposure – Non saline conditions (dry or wet, rarely dry) External concrete at least 3m above ground level, internal concrete in dry conditions, concrete permanently submerged in non-saline water or non-aggressive groundwater.

(c) Class X2: Moderate exposure – Non saline conditions (Cyclic wet and dry). External reinforced concrete less than 3m above ground level, water-retaining structures exposed to fluctuating water levels.

(d) Class X3: Aggressive exposure – Permanently submerged or wet (rarely dry) Concrete in contact with groundwater including capillary rise zone, concrete containing or permanently exposed to saline water.

(e) Class X4: Severe exposure – Moderate humidity External concrete within 1km from the sea or in contact with high saline water table or sabkhas. Concrete not affected by condensation, irrigation or leakage, which are more than 3m above ground level.

(f) Class X5: Extreme exposure – Cyclic wet and dry, external concrete within 1km from the sea or in contact with high saline groundwater or sabkhas. Concrete affected by condensation, irrigation or leakage, which are less than 3m above ground level or within capillary zone. Concrete surfaces exposed to sea water splash or in sea water tidal zone.

(g) Sulphate exposure classes S1 to S4: the exposure classes are related to sulphate attack in relation to sulphate and pH of the ground water.

2 Concrete is a mixture (mix) of cementitious materials, coarse and fine aggregate, and water, with or without admixtures, which develops its properties by cement hydration.

3 "Cementitious Materials": Portland cement in combination with one or more of the following: blended hydraulic cement, fly ash and other pozzolans, ground granulated blast-furnace slag and silica fume; subject to compliance with requirements of this specification.

4 “Water/Cementitious Ratio” shall mean the ratio between the total weight of water in the concrete (less the water absorbed by the aggregate) and the weight of cementitious materials, expressed as a decimal fraction.

5 “Admixtures” shall mean a material other than water, aggregate, cementitious materials or fiber reinforcement, used as an ingredient of concrete or mortar. Admixtures are added during the mixing process of concrete to modify the properties of the concrete mix in the fresh and/or hardened state.

6 “Hot Weather” shall mean any combination of the following conditions that tends to impair the quality of freshly mixed or hardened concrete by accelerating the rate of moisture loss and rate of cement hydration, or otherwise causing detrimental results such as: a. High ambient temperature (when the shade temperature is above 40 deg C on a rising thermometer, 43 deg C on a falling thermometer), b. High concrete temperature, c. Low relative humidity, d. High wind speed and e. whenever the rate of evaporation exceeds 0.75 kg/m^2/h

7 “Mass concrete” is defined as any volume of concrete with dimensions large enough to require that measures be taken to cope with generation of heat form hydration of the cement and attendant volume change to minimize cracking. Reinforced Massive concrete structures include pile caps, transfer plates, and structural members where the least dimension exceeds 1.5 meters.

8 “Coarse Aggregate” shall be considered as that size passing a 20mm sieve (or larger sieve size) and predominately retained on a 4mm sieve.

9 “Fine Aggregate” shall be considered as that size predominately passing a 4mm sieve and predominately retained on a 0.063mm size.

10 “PC” shall mean Portland cement or CEM I.

11 “FA” shall mean pulverised fuel ash or fly ash.

12 “GGBS” shall mean ground granulated blastfurnace slag.

13 “SF” shall mean silica fume. Other names are condensed silica fume and microsilica

14 “Gap-graded aggregate” shall mean graded aggregate without one or more of the intermediate sizes.

15 “Single-size aggregate” shall mean aggregates containing a major proportion of particles of one sieve size.

16 “Target Mean Strength” shall mean the specified characteristic strength plus the margin.

17 “Margin” shall mean the difference between the specified characteristic strength and the target mean strength.

18 “Acceptable or Accepted” shall mean acceptable or accepted by the Engineer.

19 “Approval or Approved” shall mean approval from the Engineer.

20 “All-in” aggregate shall mean the materials composed of a mixture of coarse and fine aggregates.

21 Self-Compacting Concrete (SCC): concrete that is able to flow and consolidate under its own weight, completely fill the formwork even in the presence of dense reinforcement, whilst maintaining homogeneity and without the need for any additional compaction.

6.1.4 Submittals

1 The Contractor shall submit details of mix designs to the Engineer for approval.

2 Material Safety Data Sheet MSDS or equivalent for all products. test results and other information as required to prove compliance with the specification shall be submitted to the Engineer for approval according to the relevant sections of QCS on at least the following products

3 Cement:

(a) Recent independent test results acceptable to the Engineer confirming compliance with the specified requirements and referenced standards.

(b) Manufacturer's certificates shall also be supplied for each batch of production of cement or on a weekly basis, whichever is more frequent, certifying compliance with the EN 197 or other equivalent standard.

(c) The early compressive strength of each consignment of cement shall conform to the requirements of QCS part 3 at the independent site laboratory. Deviation of more than 10% from either the previous consignment value or the rolling average shall be immediately reported to the Engineer. Testing at an independent laboratory shall be as instructed by the Engineer.

4 GGBS:

(a) Recent independent test results acceptable to the Engineer confirming compliance with the specified requirements and referenced standards.

(b) Manufacturer's certificates with all information necessary to verify compliance shall also be supplied for each consignment of GGBS or on weekly basis, whichever is more frequent.

(c) The early compressive strength of each consignment of GGBS shall be determined in accordance with EN 197 and EN 15167 or ASTM C989 at the independent site laboratory based on a blend of 50/50 % GGBS and CEM 1. Deviation of more than 5% in strength from either the previous consignment value or the rolling average shall be immediately reported to the Engineer. Testing at an independent laboratory shall be in accordance with per EN 197 and EN 15167 standards, and approved by the Engineer.

5 FA:

(a) Recent independent test results acceptable to the Engineer confirming compliance with specified requirements of EN 450 or ASTM C618.

(b) Manufacturer's certificates with all information necessary to verify compliance with internationally recognized standards shall also be supplied with each consignment of FA.

(c) The materials shall comply with QCS part 3. Deviation of the strength factor by more than 5% from either the previous consignment value or the rolling average shall be immediately reported to the Engineer and the Technical Manager of the premix company.

6 Silica fume:

(a) Recent independent test results acceptable to the Engineer confirming compliance with specified requirements and referenced standards.

(b) Manufacturer's certificates with all information necessary to verify compliance with internationally recognized standards shall also be supplied with each consignment of silica fume.

(c) 7 day pozzolanic activity test in accordance with EN 13263-1 or ASTM C 1240 on each consignment of silica fume at the Independent site laboratory. Deviation of the activity index by more than 5% from either the previous consignment value or the rolling average shall be immediately reported to the Engineer and the Technical Manager of the premix company.

7 Aggregates:

(a) Recent independent test results acceptable to the Engineer confirming compliance with the specified requirements and referenced standards.

(b) Full details of the proposed sources of aggregates.

8 Water: Recent independent test results acceptable to the Engineer confirming compliance with the specified requirements and referenced standards.

9 Admixtures: Manufacturer’s technical specifications and recommendations. Recent trial results acceptable to the Engineer illustrating the efficiency of the product for its particular application. Tests on specific gravity and solids content shall be conducted at the Independent site laboratory on each consignment.

10 Mix Designs: Submit concrete mix designs for each type and strength of concrete required at least thirty (30) days before placing concrete.

11 New mix designs, with historic data less than 6 months, shall be verified by an approved independent testing laboratory in accordance with requirements of QCS Part 05 and shall be coordinated with design requirements and Contract Documents.

12 Submit complete mix design data for each separate mix to be used on the Project in a single submittal with at least the following information:

(a) Type of cement*.

(b) Portland cement content*.

(c) Cementitious content* (GGBS, FA, natural pozzolan, rice husk ash and/or silica fume).

(d) Max. aggregate size*.

(e) Combined grading curve for coarse aggregate

(f) Quantities of all individual materials*

(g) Type of admixture(s)*

(h) Target slump/slump flow (at discharge)* as per EN 12350-2

(i) Initial and final concrete setting time for each mix design as per ASTM C403 or equivalent EN standards, if specified

(j) Fresh density of concrete as per EN 12350-6

(k) Air content as per EN 12350-7

(l) Target temperature*

(m) Bleeding, if specified

(n) Chloride and sulphate (SO_3) contents

(o) Details of calculated water/cementitious material (w/c) ratio*

(p) Compressive strength grade*

(q) Hardened density

(r) Water absorption (%) and water penetration (mm), if specified

(s) Rapid chloride permeability - Coulomb value, if specified

(t) Chloride migration coefficient (m^2/sec), if specified

*Include on delivery ticket as a minimum

13 Data shall be from the same production facility that will be used for the Project.

14 Mix Design data shall include but not be limited to the following:

(a) Locations on the Project where each mix design is to be used corresponding to Structural General Notes on the Drawings.

(b) Proportions: Concrete constituent materials shall be proportioned to yield 1 m^3

(c) Submit strength test records, mix design materials, conditions, and proportions for concrete used for record of tests, standard deviation calculation, and determination of required average compressive strength, if required by the Engineer.

(d) If early concrete strength is required, contractor shall submit trial mixture results as required.

(e) Test records to support proposed mixtures shall be no more than 12 months old and use current cement and aggregate sources. Test records to establish standard deviation may be older if necessary to have the required number of samples.

(f) Manufacturer's product data for each type of admixture.

(g) Manufacturer's certifications that all admixtures used are compatible with each other.

(h) All information indicating compliance with Contract Documents including method of placement and method of curing.

15 Mass Concrete:

(a) Submit mix design for mass concrete elements in conformance with requirements of ACI 301 Section 8. The concrete mix design shall not be designed with a high early strength unless otherwise demonstrated by the Contractor for capability of maintaining proper temperature and approved by the Engineer.

(b) Submit proposed methods of temperature control, including cementitious material content control in mix design to reduce heat-generating potential of concrete, precooling of ingredients to lower concrete temperature as placed, and methods to protect mass concrete elements from excessive temperature differentials.

(c) Submit analysis of anticipated thermal development within mass concrete elements with the proposed mix design for these elements. Results of the analysis, using methods in ACI 207.1R and ACI 207.2R such as the Schmidt model and site specific data, shall address the maximum differential temperature and the maximum temperature during curing

(d) Submit proposed number and locations of temperature monitoring devices to record temperature development between the interior and the exterior of mass concrete elements.

6.2 EXPOSURE CLASSES

6.2.1 General

1 The exposure classes are related to the environmental conditions surrounding the concrete in service.

2 The concrete may be subject to more than one of the classes described below, and the environmental conditions to which it is subjected need to be expressed as a combination of exposure classes.

3 Where two or more aggressive characteristics lead to the same class, the exposure shall be classified into the next higher class; unless a special study for this specific case proves that it is not necessary.

4 For a given structure, different concrete elements may be subject to different environmental classes.

6.2.2 Reinforcement corrosion and sulphate classes

1 The classification system described below is based on the approach in EN 206, BS 8500-1, and the Concrete Society CS 163.

2 The exposure classes related to reinforcement corrosion are associated with carbonation and chlorides as per Table 6.1.

3 The exposure classes related to sulphate attack are given in Table 6.2 in relation to sulphate and pH of the ground water.

4 The sulphate content as S04 mg/l shall be determined as per EN 196-2.

5 The pH shall be determined as per ISO 4316.

Table 6.1.
Exposure classes for reinforcement corrosion

Exposure Class	Class description
X0	**No risk of corrosion** or attack. Non saline conditions. Blinding concrete, non-reinforced concrete or slab on ground
X1	**Mild** exposure – Non saline conditions (dry or wet, rarely dry). External concrete at least 3m above ground level, internal concrete in dry conditions, concrete permanently submerged in non-saline water or non-aggressive groundwater (Class S1).
X2	**Moderate** exposure – Non saline conditions (cyclic wet and dry). External reinforced concrete less than 3m above ground level, water-retaining structures exposed to fluctuating water levels.
X3	**Aggressive** exposure – Permanently submerged or wet (rarely dry). Concrete in contact with groundwater including capillary rise zone, concrete containing or permanently exposed to saline water.
X4	**Severe** exposure – Moderate humidity. External concrete within 1km from the sea or in contact with high saline water table or sabkhas. Concrete not affected by condensation, irrigation or leakage, which are more than 3m above ground level.
X5	**Extreme** exposure – Cyclic wet and dry. External concrete within 1km from the sea or in contact with high saline groundwater or sabkhas. Concrete affected by condensation, irrigation or leakage, which are less than 3m above ground level or within capillary zone. Concrete surfaces exposed to sea water splash or in sea water tidal zone.

Table 6.2.
Sulphate exposure classes

Exposure class	Sulphate and magnesium		Natural soil		Brownfield[1]	
	2:1 water/soil and groundwater		Static water pH	Mobile water[2] pH	Static water pH	Mobile water[2] pH
	SO_4 (mg/l)	Mg (mg/l)				
S1	< 1500		> 3.5	Not mobile	> 5.5	Not mobile
S2	1500-3000		> 3.5	Not mobile	> 5.5	Not mobile
S3	3001-6000	≤ 1000	> 3.5	Not mobile	> 5.5	Not mobile
S4	> 6000	≤ 1000	> 3.5	> 5.5	> 5.5	> 6.5
S5	> 6000	> 1000	> 3.5	> 5.5	> 5.5	> 6.5

Notes

1. *Brownfield sites are those previously occupied and contain chemical residues into the ground or groundwater*
2. *The mobility of water shall be determined as described in the Concrete Society CS 163.*

6.3 FRESH CONCRETE

6.3.1 General

1 Where adequate workability is difficult to obtain at the maximum water/cementitious ratio allowed, the use of plasticisers or water reducing admixtures may be considered. Alternatively an increase in cementitious content may be considered where this will not adversely affect the durability of the concrete.

2 Cementitious contents in excess of 450 kg/m^3 shall not be used unless special consideration has been given to the effect for heat of hydration and reduce thermal stress in the concrete, and approval has been obtained from the Engineer. The maximum cementitious content shall not exceed 500kg/m^3

3 The proportioning, mixing and placing of the mixture shall be in accordance with Parts 7 and 8 of this Section

4 Temperature (at placement):

(a) Maximum fresh concrete temperature shall not exceed 32°C unless construction testing to verify a proposed concrete mixture will function satisfactorily at a concrete temperature greater than 32°C. No concrete shall be placed if the concrete temperature is above 35°C

(b) For mass concrete, the concrete producer shall demonstrate that temperature of concrete due to hydration shall comply with the maximum fresh concrete temperature specified. The supplier may use in his demonstration testing heat sensors and simulation technologies which measure the concrete heat of hydration and its rate versus concrete curing age.

5 The Contractor is responsible for ensuring that the concrete is able to be fully compacted within the concrete element regardless of reinforcing density or other limitations. This may involve reducing the maximum aggregate size, increase the level of concrete workability or use self-compacting concrete.

6 Where the consistence of concrete is to be determined, it shall be measured either by means of:

(a) Slump test conforming to EN 12350-2

(b) Flow table test conforming to EN 12350-5

7 The consistence of concrete shall be determined at the time of use of the concrete or in the case of ready-mix concrete, at the time of delivery.

8 The tolerances for the different consistence tests and target values are given in Table 6.3.

Table 6.3.
Tolerances for target values of consistence

Slump*	Target value (mm)	≤ 40	50 to 90	≥ 100
	Tolerance (mm)	-30, +40	-40, +50	-50, +60
Flow diameter*	Target value (mm)	All values		
	Tolerance (mm)	-60, +70		

* For spot samples taken from initial discharge.

6.4 GRADES OF CONCRETE

1 Where strength is classified with respect to compressive strength, Table 6.4 gives the concrete grade with the requirements for w/c ratio and cementitious content.

2 Higher compressive strength than C75 would require special approval from the Engineer and the consultant.

3 The characteristic compressive strength at 28 days of 150mm or 100mm cubes (f_{ck}, cube) or 150mm diameter by 300mm cylinders (f_{ck}, cyl) may be used for the classification.

4 Exception will be made for concrete mixtures containing fly ash, silica fume or GGBS, where testing shall be requested at 56 days, or 90 days as approved by the Engineer.

Table 6.4:
Concrete grades and composition requirements

Concrete Grade	Minimum characteristic cube strength (fck, cube) (N/mm^2)	Minimum characteristic cylinder strength (fck, cyl) (N/mm^2)	Minimum cementitious content (kg/m^3)	Maximum Water : Cementitious Ratio (w/c)
B 15	15	12	-	-
B 20	20	16	-	-
C 25	25	20	260	0.65
C 30	30	25	300	0.58
C 35	35	28	320	0.55
C 40	40	32	335	0.50
C45	45	35	355	0.47
C 50	50	40	370	0.45
C 60	60	50	380	0.40
C 75	75	60	390	0.35

6.5 DURABILITY REQUIREMENTS

6.5.1 General

1 Durability is not a property but rather an overall performance of the concrete and could vary based on the quality of its constituents, mix design, construction practice and exposure environments.

2 Durability is the ability of concrete to last a long time resisting weathering action, chemical attack, and abrasion(exposure conditions) while maintaining without significant deterioration. A durable concrete enables conserving resources and reducing wastes and the environmental impacts of repair and replacement.

3 Constituent materials shall not contain harmful ingredients in such quantities as may be detrimental to the durability of concrete or cause corrosion of the reinforcement.

4 For reinforced concrete in the ground, the need for protection from chlorides must be balanced against the need for protection from sulphates.

5 Protective measures include the use of surface treatment, alternative reinforcement and increasing the concrete cover. In every case, the need for good quality concrete with low permeability is paramount.

6

6.5.2 Maximum acid soluble chloride content

1 The chloride content of the concrete, expressed as the percentage of chloride ions by mass of cementitious materials, shall not exceed the values given in Table 6.5.

2 Calcium chloride and chloride based admixtures shall not be used in concrete containing steel reinforcement or other embedded metal.

3 The determination of the chloride content in the concrete shall be conducted by the sum of the contributions from the constituent materials as described in EN 206 and BS 8500-2.

Table 6.5.
Maximum chloride content of concrete (by weight of cementitious materials)

Concrete type	Concrete made with sulphate resisting Portland cement	Concrete made with other cementitious materials than SRPC
Reinforced concrete	0.15 %	0.3 %
Pre-stressed concrete	0.08 %	0.10 %

6.5.3 Type of cementitious material

1 Different types of cementitious materials offer different resistance to sulphate attack and penetration of chlorides

2 The minimum cementitious content for different concrete grades is given in Table 6.4.

3 Table 6.6 gives the different types of cementitious materials and their combinations.

Table 6.6.
Cementitious materials and combinations

Cementitious material	Percentage of components	EN 197-1 designation	ASTM standard
Portland cement	100% PC	CEM I	Type 1
Sulphate-resistance Portland cement	100% SRPC	-	Type 5
PC/SF	90-95% PC 10-5% SF	CEM II/A-D	
PC/fly ash	65-79% PC 35-21% FA	CEM II/B-V	
PC/ground granulated blastfurnace slag	35-65% PC 65-35% GGBS	CEM III/A	
Triple blend PC/FA/SF	55-70% PC 35-25% FA 10-5% SF		
Triple blend PC/GGBS/SF	30-45% PC 60-50% GGBS 10-5% SF		

6.5.4 Resistance to alkali-silica reaction

1 Alkali-silica reaction is the most common form of alkali-aggregate reaction.

2 Dry concrete is not prone to cracking by alkali-silica reaction, as it needs an external source of water to develop sufficiently to cause cracking.

3 Where aggregate contain varieties of silica susceptible to attack by alkalis from cement and other sources and the concrete is exposed to humid conditions, actions shall be taken to prevent deleterious alkali-silica reaction using recommendations and procedures given in EN 206 and BS 8500-2.

6.5.5 Recommendations to resist reinforcement corrosion

1 Durability design should start at the concept design stage, continuing through the design, detailing, specification and execution phases.

2 This section covers the concrete grade, cementitious type, and minimum concrete cover for various exposure classes as given in Table 6.1.

3 Table 6.7 provided recommended values of concrete grade and cover thickness to resist reinforcement corrosion at different exposure classes.

Table 6.7.
Recommended durability requirement to resist reinforcement corrosion

Exposure Class		Minimum concrete cover (mm)					Cementitious type (Table 6.6)
X0	No risk of corrosion	25					All
X1	Mild	45	40	35	30		All
X2	Moderate	-	50	45	40	35	All
X3	Aggressive	-	70	65	60	55	– PC/FA – PC/GGBS – PC/SF – Triple blend
X4	Severe*	-	75	70	65	60	– PC/FA – PC/GGBS – PC/SF – Triple blend
X5	Extreme*	-	80	75	70	65	– Triple blend
Recommended concrete grade		C30	C40	C50	C60	C75	

- *High level of cement replacement is required for severe and extreme exposure conditions. Other protection measures such as coated reinforcement or surface treatment may be considered.

6.5.6 Recommendations to resist sulphate attack

1 The exposure classification shall be identified based on the sulphate and magnesium contents in the ground and groundwater, pH and mobility of groundwater as given in Table 6.2.

2 The recommended concrete specification requirements in terms of concrete grade and cementitious type are given in Table 6.8.

3 Unless stated otherwise by the Engineer or project designs, all concrete below ground shall have surface protection to prevent the movement of moisture from the ground, through the foundations into the superstructure. The method of protection shall be in accordance with Section 15 of the QCS or as approved by the engineer.

Table 6.8
Recommended durability requirement to resist sulphate attack

Exposure class	Minimum concrete grade	Cementitious type
S1	C35	All
S2	C40 C50	Triple blend SRPC, PC/FA, PC/GGBS, PC/SF
S3	C50 C60	Triple blend SRPC, PC/FA, PC/GGBS, PC/SF
S4	C60 C75	Triple blend
S5[1]	See Note	See Note

Note:
S5[1] requires special treatment when the sulphate content exceeds 6000 mg/l and the magnesium content exceeds 1000 mg/l.

6.5.7 Durability-Related Properties

1 The durability of concrete is greatly influenced by the ability of the concrete cover to resist the movement of liquid and gas through concrete.

2 The commonly used test for assessing the transport properties of concrete are listed in Table 6.9 together with typical values. Lower value indicates more durable concrete.

3 The proposed test methods do not always relate to each other. Consideration should be given to the applied-voltage tests when assessing concrete with new/different ingredients.

4 The Engineer shall assess the exposure classes (Tables 6.1 and 6.2) before considering the durability requirements.

5 Table 6.9 gives the recommended durability-related properties and typical range values for the development of mix design and comparative performance as given in the Concrete Society CS163. High durability indicates more resistance to the surrounding environment.

6 For Severe and Extreme exposures, it is recommended to use high durable concrete (Table 6.9)

Table 6.9
Recommended properties and range values for concrete

No.		**Recommended Durability Range[1]**			
		High Level	Moderately Level	Low Level	
1	Concrete Exposure Condition[1]	X4, S4, X5[3] ,S5[3]	X2, S2, X3, S3	X1, S1	X0,
	Recommended Durability Range [2]	**Typical Range for Durability Requirement @ 28 days concrete age**			
2	Water Absorption, BS 1881: Part 122 (%)	< 1.5	1.5 – 3.0	> 3.0	N.A
2	Water Penetration, EN 12390-8 (mm)	< 10	10 – 25	> 25	N.A
3	Resistance to Chloride ion Penetration (RCP) [4], ASTM C 1202 (coulombs)	< 1000	1000 – 4000	> 4000	N.A
4	Chloride Migration[4], NT Build 492 (m^2/s)	< 2.0×10^{-12}	$(2.0 – 9.0) \times 10^{-12}$	N.A	N.A

1. For any exposure condition and upon the Engineer approval, the consultant may request a higher durability level, or higher range of any requirement, or any protection measures such as coated reinforcement or surface treatment to enhance the durability of concrete.
2. Concrete shall be tested as requested by the Engineer, and shall be tested at 28 days, exception shall be made for concrete mixtures containing fly ash, silica fume or GGBS, where testing shall be requested by the engineer at 56 days, or 90 days
3. Other protection measures such as using coated reinforcement or surface treatment or any other enhancing technology for concrete properties shall be considered.
4. Unsatisfactory test results shall not be liable to reject the concrete

6.6 DESIGN OF CONCRETE MIXES

1 At the start of the construction period, the Contractor shall design a mix for each grade of concrete as stated hereafter.

2 Each mix design shall be such that:

(a) the aggregate shall comprise fine aggregate and coarse aggregate with size specified in Section 5, Part 2.

(b) the combined aggregate grading shall be continuous

(c) the aggregate quantity shall be calculated by weight.

3 Where a concrete production facility has strength test records not more than 12 months old, a sample standard deviation, S_s, shall be established. Test records from which S_s is calculated shall consist of at least 30 consecutive tests or two groups of consecutive tests totalling at least 30 tests

4 Where a concrete production facility does not have strength test records meeting requirements of 6.6 (3) above, but does have test records not more than 12 months old based on 15 to 29 consecutive tests, a sample standard deviation S_s shall be established as the product of the calculated sample standard deviation and modification factor of Table 6.10

Table 6.10
Modification Factor for Sample Standard Deviation When Less Than 30 Tests Are Available

No. of tests	Modification factor for sample standard deviation
Less than 15	Use para 7. Below
15	1.16
20	1.08
25	1.03
30	1.00
1- Interpolate for intermediate number of tests 2- Modified sample standard deviation, S_s, to be used to determined required average strength f'_{cr}	

5 To determine the correction factor between cube strength and cylinder strength, the contractor shall establish at least 30 consecutive strength tests from each proposed mix design. This correction will remain valid through the project provided that no change in the properties of the materials and no change in source occurred.

6 Required average compressive strength (Target Mean Strength) f'_{cr} used as the basis for selection of concrete proportions shall be determined from Table 6.11 using the sample standard deviation, S_s

Table 6.11:
Required Target Mean Strength when data are available
to establish a sample Standard Deviation

Specified cylinder compressive strength, N/mm^2 or MPa	Required average compressive strength, Target Mean Strength, N/mm^2 or MPa
$F'c \leq 35$ MPa --- see footnote	$F'cr = f'c + 1.65S_s$ ---------- Eq. 1 $F'cr = f'c + 2.33S_s - 3.5$ ---------- Eq. 2
$F'c > 35$ MPa --- see footnote	$F'cr = f'c + 1.65S_s$ ---------- Eq. 1 $F'cr = 0.90f'c + 2.33S_s$ ---------- Eq. 3

Note: Use the larger value computed from any equation

7 When a concrete production facility does not have field strength test records for calculation of S_s, Required average strength (Target Mean Strength) f'cr shall be determined as follow:

(a) F'cr = f'c + 8.5 MPa when 20 < f'c ≤ 35 MPa

(b) F'cr = 1.10f'c + 5 MPa when f'c > 35 MPa

6.6.1 Concrete

1 Portland cement concrete shall consist of a mixture of cementitious materials, fine aggregate, coarse aggregate, water, and additives (when required). It shall be classified as in Table 6.4 unless otherwise stated hereafter and requested by the Engineer.

2 Blinding concrete

(a) Blinding concrete shall be of minimum Grade C15 and above.

(b) The thickness of the blinding concrete shall be as shown on the Drawings, but shall in no instance be less than 75 mm.

(c) The surface finish to blinding concrete shall be Class U4 as specified in Clause 9.3.1 of Part 9 of this Section or as directed by the Engineer.

3 Mass Concrete

(a) The fresh concrete temperature at placing shall not exceed 27°C to minimise thermal cracking. The maximum allowable differential temperature between the interior and the exterior of the mass concrete element shall not exceed 20° C. The maximum temperature in any location within the mass concrete structure during curing shall not exceed 70 °C. The drop in concrete surface temperature during, and at the conclusion of the specified curing period, shall not exceed 11 °C in any 24 hour period.

4 Self-Compacting Concrete

(a) General: Self-Compacting Concrete (SCC) is a special concrete that requires minimum or no vibration for placing and compaction. It is able to flow under its own weight, completely filling formwork and achieving full compaction, even in the presence of congested reinforcement. The hardened concrete is dense, homogeneous and has the same engineering properties and durability as traditional vibrated, fully compacted concrete.

(b) Self-Compacting Concrete Supplier: SCC shall be supplied by a competent concrete producer with a record of successfully producing this type of concrete at considerable volume and with high consistency.

(c) Constituent Materials, General: The constituent materials for SCC are the same as those used in traditional concrete conforming to EN 206, as specified in part 2 of this section.

(d) To achieve these requirements, the control of the constituent materials needs to be increased and the tolerable variations restricted, so that daily production of SCC is within the conformity criteria without the need to test and/or adjust every batch.

(e) Recommended Test Requirements for SCC:

	Laboratory tests	Field Tests
Slump-flow	600 – 750 mm	550 – 750 mm
V-Funnel	6 – 25 sec	N.A
L-Box (3 bars)	$\geq$ 0.80	N.A
J-Ring	$\leq$ 10mm	N.A

(f) Concrete specimens shall be moulded in single layer without rodding and tapping

(g) Slump flow and VSI testing shall be performed as outlined in the European Guidelines for SCC, EN 12350-8 and EN 12350-9 or ACI 237R 07 and ASTM C 1611/C 1611M

5 Pile Concrete

(a) The cementitious content shall not be less than 380 kg/m^3, as specified in Section 4.

(b) The water-cementitious ratio shall not exceed 0.45

(c) The concrete mixture shall be designed of high slump not less than 150 mm allowing proper free fall with excellent homogeneity. When concrete mixture requires slump of greater than 230 mm, it shall be designed as Self-Compacting Concrete or as instructed by the Engineer.

(d) The concrete slump shall have adequate workability retention using approved type of retarder and shall be submitted in the design mix.

(e) The increase in workability shall not permit any decrease in the specified design strength

(f) The concrete in a pile shall, if at all possible, be placed in one continuous operation.

6 Underwater Concrete

(a) Shall comply with ACI 304 Chapter 8

(b) The Cementitious content shall not be less than 390 kg/m^3

(c) The water-cementitious ratio must not exceed 0.40

(d) Fine aggregate contents of 45 to 55% by volume of total aggregate and air contents of up to approximately 5% are generally specified.

(e) Concrete shall be more cohesive and less prone to washout of cement or fines from the concrete during placement. Antiwashout admixtures or alternative concrete mix shall be used for underwater concrete.

(f) Trial placements shall be conducted to verify that the concrete proportioned with the antiwashout admixture can maintain adequate slump life and can flow for the required distance.

(g) The concrete mixture shall be designed of high slump not less than 150 mm allowing proper free fall with excellent homogeneity. The use of air-entraining admixture shall be evaluated as it increases the workability. When concrete mixture requires slump of greater than 230 mm, it shall be designed as Self Compacted Concrete. The increase in slump shall be made using proper admixtures.

(h) The concrete slump shall have adequate retention using approved type of retarder and shall be submitted in the design mix.

(i) The increase in workability shall not permit any decrease in the specified design strength

(j) The concrete shall be placed in one continuous operation

(k) The final selection of a concrete mixture shall be based on test placements made under water in a placement box or in a pit that can be dewatered after the placement. Test placements shall be examined for concrete surface flatness, amount of laitance present, quality of concrete at the extreme flow distance of the test, and flow around embedded items, if appropriate.

7 Shotcrete

(a) The classification of shotcreting shall be in accordance to the process used (wet-mix or dry-mix) and the size of aggregates used.

(b) All materials shall be as per QCS except for aggregate where gradation shall be as per ACI 506R and 506.2R

(c) Steel and synthetic fibers will be used to reduce propagation of cracks. Fibers shall be as per Manufacturer supplier data sheet and shall conform to ASTM A 820 for steel fibers and ASTM C1116 for synthetic fibers, other fibers shall be approved by the engineer.

(d) The nozzle operator should be certified (refer to ACI CP-60) and have completed at least one similar application as a nozzle operator on a similar project. The nozzle operator should also be able to demonstrate, by test, an ability to satisfactorily perform the required duties and to apply shotcrete as required by specifications

(e) Before shotcreting the surface shall be prepared and maintained before and during shotcrete application. Surface preparation shall conform to ACI 506 R chap. 5

(f) The cementitious content shall not be less than 360 kg/m^3 where wet-mix is applied the slump shall be in the range of 40 to 80 mm

(g) Normal testing ages for compressive strength are 7 and 28 days; however, shorter periods may be required for particular applications or conditions as directed by the Engineer. Testing shall be on daily production or every 30 m^3 whichever is greater.

(h) Sampling and testing, however, should be varied according to the size and complexity of the project. Sampling should be done in accordance with ASTM C 1385. Making extra cylinders or panels shall be at the request of Engineer if testing results vary.

(i) Testing for water absorption and drying shrinkage shall be at the request of the Engineer.

(j) Fiber-reinforced shotcrete requires fiber washout tests or flexural toughness testing according to ASTM C 1018.

(k) Acceptance of shotcrete should be based on results obtained from drilled cores or sawed cubes (ASTM C 42). The use of data from nondestructive testing devices, such as impact hammers or probes (ASTM C 805, ASTM C 803), ultrasonic equipment (ASTM C 597), and pull-out devices (ASTM C 900) may be useful in determining the uniformity and quality of the in-place shotcrete. These tests, however, may not provide reliable values for compressive strength.

(l) Core grading is a method used to evaluate encasement of reinforcement. Core grading shall be used for nozzle operator evaluation. Core grading should not be used to evaluate structures.

8 No-Fines Concrete and Pervious concrete

(a) No-fines concrete shall be made using a coarse aggregate conforming QCS section 5 part 2

(b) Proportion of aggregate, cement and water shall be determined by trial mixes by the Contractor and to be accepted by the Engineer.

(c) All the aggregate particles are to be coated with a film of cement grout.

(d) No-fines concrete when placed shall contain no layers of laitance.

(e) No-fines concrete shall not be mixed by hand.

(f) Mechanical vibration shall not be used to compact no-fines concrete.

(g) Three test cubes of no-fines concrete shall be made of each preliminary mix.

(h) Minimum crushing strength of the chosen mix shall be 5 MPa at 28 days.

(i) The porosity of no-fines concrete shall be such that water will pass through a slab 300 mm thick at the rate of not less than 7 l/m^2 • s of slab with a constant 100 mm depth of water on the slab.

(j) Where a slab incorporating vertical weep holes or drain holes is casted above a layer of no-fines concrete; any polyethylene sheeting shall be pierced below the pipes forming such drain holes and the edges of the sheeting sealed to the lower end of the pipe to prevent the ingress of grout and fine particles from the slab concrete into the no-fines concrete.

(k) The limit for the maximum height of drop while placing is not applicable for no fines concrete.

(l) Formwork shall remain in place until the no fines concrete has gained adequate strength to support itself as per the requirements of Part 10 of this Section.

(m) Curing shall be carried out in accordance with the provisions of Part 11 of this Section

(n) The fresh density of Pervious concrete shall be tested as per ASTM C1688 and the infiltration rate shall be tested as per ASTM C1701 and to follow ACI 522.1R for testing and quality control scheme.

9 Concrete with recycled aggregates shall be generally approved once the source of recycled aggregates is identified based on type and approved by the Engineer.

(a) The recycled aggregates shall meet with EN 12620 and QCS requirements.

(b) The concrete made with recycled aggregates shall be limited to design strength of C40 MPa cube strength; unless otherwise accepted by the Engineer. EN 206 shall be the code of practice and guide for the usage of recycled concrete aggregates in concrete or ACI 555 and BRE digest 433.

(c) The Water-cementitious ratio shall not exceed 0.50

(d) To determine a target mean strength on the basis of a required strength, a higher standard deviation (increased by 40%) shall be used when designing a concrete with recycled aggregates of variable quality than when recycled aggregate of uniform quality or virgin aggregates are used

(e) Specific gravity, unit weight, and absorption of aggregates should be determined before mixture proportion studies

(f) The mixture proportion should be based on the measured density of the recycled aggregates intended in the job concrete

(g) Trial mixes shall be made to verify the requirements with project specification and QCS.

10 Heavyweight and radiation shielding concrete

(a) The quality of the aggregates should comply with the requirements of QCS for normal weight aggregates, ASTM C 637 for heavyweight aggregates and ASTM C638 for aggregates to be used in radiation-shielding concrete.

(b) When ferrophosphorous aggregates are used, tests shall be made to determine if gases (nontoxic) might be released during construction.

(c) Aggregates shall be checked for every delivery to ensure that they conform completely with purchase specifications

(d) Aggregates shall be frequently evaluated for the effects of deleterious substances or aggregate coatings on concrete strength or the promotion of corrosion in metallic aggregates or embedment's

(e) The chemical properties of all high-density aggregates must be provided to the Engineer for evaluation before use with due consideration given to chemical reactivity, particularly in highly alkaline environment as found in cement paste.

(f) Tests for alkali-aggregate reactivity shall be determined from each source and supplier and shall be made every 3 months.

(g) The fresh density of high-density concrete shall be made from each truck

(h) Lead shot concrete shall not be use for structural concrete.

(i) Thermal conductivity, elastic behaviour and shrinkage, hardened density, strength as well as other hardened concrete properties shall be tested and verified before the use of concrete.

11 Fiber-Reinforced Concrete

(a) Classification of fiber-reinforced concrete shall be made based on the material type of the fiber incorporated:

(i) Type I Steel Fiber-Reinforced Concrete—Contains stainless steel, alloy steel, or carbon steel fibers conforming to Specification of EN 14889-1 or ASTM A820 /A820M .

(ii) Type II Glass Fiber-Reinforced Concrete—Contains alkali-resistant (AR) glass fibers conforming to Specification C 1666/C 1666M.

(iii) Type III Synthetic Fiber-Reinforced Concrete— Contains synthetic fibers for which documentary evidence can be produced confirming their long-term resistance to deterioration when in contact with the moisture and alkalis present in cement paste and the substances present in admixtures and shall conform to EN 14889-2

(iv) Type IV Natural Fiber-Reinforced Concrete— Contains natural fibers for which documentary evidence can be produced confirming their long-term resistance to deterioration when in contact with the moisture and alkalis present in cement paste and the substances present in admixtures. Test Method ASTM D 6942 shall be used to determine the susceptibility of these fibers to deterioration as a result of exposure to alkalis in concrete

(v) When the purchaser chooses to permit the use of fibers other than those complying with the above classifications, the manufacturer or supplier shall show evidence satisfactory to the purchaser that the type of fiber proposed for use shows long-term resistance to deterioration when in contact with the moisture and alkalis present in cement paste and the substances present in admixtures

(b) The contractor shall submit:

(i) Type of fiber-reinforced concrete required

(ii) Designated size, or sizes, of coarse aggregates

(c) Slump or time of flow required at the point of delivery, or when appropriate the point of placement, subject to the tolerances hereinafter specified Slump shall be specified when it is anticipated to be 50 mm or more. Except as otherwise specifically permitted by the Engineer, cement, supplementary cementitious materials, fine and coarse aggregates, mixing water, and admixtures shall be measured in accordance with the applicable requirements of QCS

(d) Fibers shall be measured by mass. When the fibers are to be measured by mass, bags, boxes, or like containers are acceptable provided that such like containers are sealed by the fiber manufacturer and have the mass contained therein clearly marked. No fraction of a container delivered unsealed, or left over from previous work, shall be used unless weighed.

(e) Prepackaged, dry, combined materials, including fibers, shall comply with the packaging and marking requirements of Specification ASTM C 387 or C 1480 and shall be accepted for use provided that after addition of water, the resulting fiber reinforced concrete meets the performance requirements of this specification

(f) Batching plant used for the preparation of continuously mixed fiber-reinforced concrete shall comply with the applicable requirements of NRMCA. Fiber-reinforced concrete shall be added directly to the concrete at the time of batching in amounts in accord with approved submittals for each type of concrete required. Mix concrete in strict accord with fiber-reinforced concrete manufacturer, instructions and recommendations

(g) Fiber-reinforced concrete shall be free of fiber balls when delivered

(h) The manufacturer of the fiber-reinforced concrete shall furnish to the purchaser a delivery ticket or statement of particulars on which is printed, stamped, or written, information with details of the type, brand, and amount of fibers used.

(i) The contractor shall afford the inspector all reasonable access, without charge, for the procurement of samples of freshly mixed fiber-reinforced concrete at the time of placement to determine compliance with the requirements of this specification.

(j) Samples of batch-mixed fiber-reinforced concrete shall be obtained in accordance with Practice ASTM C 172 or C 1385/C 1385M for shotcrete as appropriate, except that wet-sieving shall not be permitted. Sampling for uniformity tests shall be in accordance with specification ASTM C 94/C 94M

(k) If the measured slumps, time of flow, or air content fall outside the limits permitted by this specification, make a check test immediately on another portion of the same sample. If the results again fall outside the permitted limits, the material represented by the sample fails to meet the requirements of this specification

(l) The following shall apply to all forms of fiber-reinforced concrete except dry-mix shotcrete. When applicable, the slump shall be in tolerance with this section para 6.4.2.5 (a) and (b).

(m) The time of flow shall be in the tolerances as follow:

(i) When the project specifications for time of flow are written as a “minimum” or “not less than” requirement

	Specified time of flow	
	If 15sec or less	If more than 15 sec
Plus Tolerance	5s	10s
Minus Tolerance	0s	0s

(ii) When the project specifications for time of flow are not written as a “minimum” or “not less than” requirement:

Tolerances for time of flow	
For specified time of flow	Tolerance
8 to 15 s	± 3s
More than 15 s	± 5s

(n) Finishability - Pre-project trials shall be utilized to determine acceptable surface finishability by the Engineer. The manufacturer shall provide the services of a qualified technician to instruct the concrete supplier in proper batching and mixing of materials to be provided.

(o) Provide fibers for concrete reinforcing capable of achieving a two hour fire resistance rating when tested under ASTM E 119. Fire tests must be certified.

12 Lightweight concrete

(a) This clause of the specification refers to lightweight concrete with improved insulation properties where the practical range of densities is between about 300 and 1850 kg/m3.

(b) The required density and strength of the lightweight concrete will be specified on the drawings or directed by the Engineer.

(c) The method of production of lightweight concrete will be shown on the drawings or directed by the Engineer. The Contractor shall submit full technical details of the materials and method of production for the lightweight concrete along with a list of previous projects where the particular system has been used.

(d) After source approval of the material and system the Contractor shall submit a mix design for the lightweight concrete for the approval of the Engineer. After the review and approval of the mix theoretical mix design the Contractor shall carry out a trial mix to check the workability of the fresh concrete and to allow samples to be made for compressive strength and density.

(e) The Engineer may also instruct that tests are carried out for abrasion resistance and thermal insulation properties.

(f) lightweight concrete shall be made with lightweight aggregates as approved in part 2 of section 05 in QCS for its use in concrete, or approved by the engineer and designer.

(g) The performance of lightweight concrete shall follow ACI 213R

6.7 TRIAL MIXES

1 As soon as the Engineer has approved the concrete mix design for each grade of concrete and during or following the carrying out of the preliminary tests, the Contractor shall prepare a trial mix of each grade in the presence of the Engineer at least 35 days before commencement of concreting. Trial mix shall be mixed and handled by means of the same plant which the Contractor proposes to use in the Works. The trial mix shall comprise not less than 50% from the central mixing drum capacity but not less than 3.0 m^3 of concrete. The trial mix can be exempted if concrete supplier provides through an independent approved testing agency adequate history on strength:

(a) Not less than 30 strength test results as in para 6.6 of this specification

(b) The results shall valid by no more than 6 months from the date of approval

2 Batch the field concrete trial mixture within -5°C of the proposed maximum allowable fresh concrete temperature in a truck-mixer with a minimum batch size of 3 m^3.

3 The concrete mixture shall be held in the mixer for 120 minutes, unless otherwise specified by the Engineer. During the entire 120-minute period, agitate the mixer at 1 to 6 rpm. At the end of 120 minutes, mix the concrete mixture at full mixing speed designated by the manufacturer (6 to 18 rpm) for 2 minutes.

4 For each trial mix, a plant production trial shall be carried out and the slump of the concrete checked immediately after discharge from the mixer and thereafter at 30 min intervals up to the maximum time period envisaged for delivery and standing on site. Based on this trial the mix design shall identify any adjustments to the range of plasticiser for acceptable workability for different times after batching. Where ready mix concrete is being used, the above requirement may be waived at the discretion of the Engineer if the Contractor has documented previous experience of a particular mix design with test results available.

5 The proportions of cement, aggregate and water shall be carefully determined by weight in accordance with the Contractor's approved mix design (or modified mix design after preliminary tests).

6 Each sample shall consist of at least 9 specimens for strength analysis where 3 specimens for each age will be tested to determine the concrete strength at the required age.

7 If either or both the average value of the strength of the three cubes tested at 28 d is less than the required strength (target strength) or the difference between the greatest and the least strengths is more than 15 % of the average strengths, as per EN 206, the Contractor shall take measures as deemed necessary such as:

(a) Propose new mix design

(b) Provide new materials and prepare and test further trial mixes until specified requirements are achieved.

8 Additionally, the Contractor shall measure the temperature, workability of concrete in each batch.

9 When requested by engineer, a mock-up of 2x2x2 m^3 shall be made at jobsite and full scale tests of the workability of each trial mix shall be made by the Contractor in the presence of the Engineer. The following tests shall be made on the Site by filling trial moulds to confirm the suitability of:

(a) mix for the works

(b) type of plant used for mixing

(c) face intended for use in the works

(d) type of form oil

(e) type of protective coatings.

10 Redesign of the concrete mixes and trial mixes of concrete shall be repeated for each grade of concrete until the concrete meets the requirements in this specification and it is verified by full scale mockup test as described above.

11 Approval of the job-mix proportions by the Engineer or his assistance to the Contractor in establishing those proportions, in no way relieves the Contractor of the responsibility of producing concrete which meets the requirements of this Specification.

12 All costs connected with the preparations of trial mixes and the design of the job mixes shall be borne by the Contractor.

13 The Contractor shall declare any change in the source of the material and any changes in the cement content consumption greater than 20.0kg/m³ from that used in the trial mixes.

6.8 QUALITY AND TESTING

6.8.1 General

1 In order to ensure that the quality of materials and mix proportions are maintained throughout concreting operations, sampling and testing shall be carried out using the relevant standard procedures and all other relevant codes quoted in this specification in accordance with a routine testing program that shall be agreed with the Engineer before the start of concrete work.

2 The Contractor, through a third party approved testing agency, shall supply all necessary tools for tests, shall cast all concrete specimens, strip and store them in water as stated in EN 12390-2. The Contractor shall also arrange for the transport of samples to the place of testing and shall supply the Engineer with duplicate copies of all test certificates.

6.8.2 Tests for Concrete

1 Unless the Engineer directs otherwise, the program shall include at least the tests specified below.

2 Tests on aggregates shall be as described in Part 2 of this Section.

3 Concrete shall be tested in accordance with the requirements of this specification by qualified field testing technicians or engineer. Concrete testing laboratory personnel shall be certified from a recognised Institution. Field personnel's in charge of sampling concrete; testing for slump, and temperature; and making and curing test specimens shall be certified from a recognised Institution too.

4 Slump tests (and VSI testing when applicable) shall be carried out at the rate of one test per load of concrete delivered to the Site, or one test per 10 m^3 whichever is the lesser for the first 50 m^3 of concrete then at a rate of 1 slump test for every 50 m^3 if concrete was consistent during production. In the event of inconsistent slump values, the Engineer may instruct the Contractor to check the slump test on each truck of concrete at the plant. The Contractor shall carry out an investigation to establish the cause of the high variation in slump and shall take any necessary corrective measures. The slump requirements for the fresh concrete are to be approved by the Engineer.

5 The adjustment for the slump of concrete to fit the job requirement can be conducted only one time using a proper additive at jobsite provided that such addition does not increase the water-cement ratio and setting time above the maximum permitted by the specifications. This addition will only be made at the approval of Engineer.

6 Concrete shall be available within the permissible range of slump for a period of 30 min starting either on arrival at the job site or after the initial slump adjustment as permitted above, whichever is later. The first and last quarter m^3 discharged are exempt from this requirement. If the user is unprepared for discharge of the concrete from the vehicle, the producer shall not be responsible for the limitation of minimum slump after 30 min have elapsed starting either on arrival of the vehicle at the prescribed destination or at the requested delivery time, whichever is later.

7 When air-entrained concrete is desired the purchaser shall specify the total air content of the concrete. The air content of air-entrained concrete when sampled from the transportation unit at the point of discharge shall be within a tolerance of ±1.5% of the specified value.

8 Concrete strength test:

(a) Each concrete strength sample shall consist of at least seven specimens, two to be tested at 7 days, three at 28 days and two to be tested at the discretion of the Engineer. Additional samples may be prepared as directed by the Engineer to be tested at the discretion of the Engineer for strength and/or durability.

(b) When concrete cylinders have been specified, the concrete specimens shall not be capped using sulphur for environmental effect. The Contractor shall follow one of the following procedures and as approved by the Engineer:

(i) Cap the specimens in accordance with ASTM C617 using neat cement paste and/or High-strength gypsum cement paste

(ii) Saw cut and Grind the surface of the concrete to the desired planeness and perpendicular

(iii) Test the concrete cylinders using Unbonded Caps in accordance with ASTM C1231

(iv) For field specimens, the contractor has the right to either use the conversion listed in EN 206 or determine the conversion factor for each specified concrete mix design by testing at least 36 comparative specimens (i.e. 18 cubes versus 18 cylinders sampled from 3 consecutive batch trial mix).

(c) A minimum of one sample shall be taken of each mix every day the mix is used

(d) Samples shall be taken at the average rate of the followings:

(i) One sample every 30 m^3, if the pour is less than or equal to 90 m^3

(ii) One sample every 100 m^3, if the pour is greater than 90m^3 and equal to or less than 2000 m^3,

(iii) One sample every 200 m^3, if the pour exceeds 2000 m^3.

(e) Test specimens for compressive strength testing shall be prepared and cured in accordance with EN 12390-2. The compressive strength of the specimens shall be determined in accordance with EN 12390-3.

(f) A test shall be the average of the strength of the specimens tested at the age specified. If a specimen shows definite evidence other than low strength, of improper sampling, moulding, handling, curing, or testing, it shall be discarded and the strength of the remaining cubes shall then be considered the test result.

(g) Acceptance criteria of concrete strength shall be assessed for compliance with ACI 214 and EN 206 or ACI 318 and explained below:

EN 206

(i) The average strength tests (average of two specimens or more) shall be equal to or greater than the characteristic (f_{ck}) + 2 MPa, and

(ii) Any individual test result shall be equal to or greater than f_{ck} – 4 MPa. The test result shall be that obtained from the average of the results of two or more specimens made from one sample for testing at the same age.

ACI 318

(i) A test shall be the average of the strengths of the specimens tested at the age specified. If a specimen shows definite evidence other than low strength, of improper sampling, moulding, handling, curing, or testing, it shall be discarded and the strength of the remaining specimens shall then be considered the test result and where the range of the test values is more than 15 % of the mean, the results shall be disregarded unless an investigation reveals an acceptable reason to justify disregarding an individual test value. To conform to the requirements of this specification, strength tests representing each class of concrete must meet the following requirements:

(ii) The average of any three consecutive strength tests shall be equal to, or greater than, the specified strength, f ‘c, and

(iii) When the specified strength is 35 MPa or less, no individual strength test (average of at least two specimen tests) shall be more than 3.5 MPa below the specified strength, f ‘c

(iv) When the specified strength is greater than 35 MPa, no individual strength test (average of two specimen tests) shall be less than 0.90 f ‘c.

9 If works test specimens fail at 28 days the Contractor shall suspend concreting operations and shall not proceed further without approval. The Contractor shall carry out in-situ testing of the suspect concrete in accordance with Part 13 of this Section, in the presence of the Engineer. All defective work shall be replaced and retested to the satisfaction of the Engineer.

6.8.3 Hardened Tests for Fiber-Reinforced Concrete

(a) When post-crack flexural performance is used as the basis for acceptance of fiber-reinforced concrete, make, condition, and test sets of test specimens in accordance with Test Method ASTM C1399, C1550 or C1609/C1609M as specified.

(b) When flexural strength is used as the basis for acceptance, make and test sets of at least three test specimens in accordance with the requirements for sampling and conditioning given in Test Method ASTM C1609/C1609M. Test specimens representing thin sections, as defined in C1609/C1609M, or specimens representing fiber-reinforced shotcrete of any thickness, shall be tested as cast or placed without being turned on their sides before placement on the support system. Acceptance shall not be based on flexural strength alone when post-crack performance is important. Test Method C1609/C1609M provides for the determination of first peak flexural strength when required by the purchaser. For many type-amount fiber combinations, the first peak flexural strength is not significantly greater than the peak strength in flexure.

(c) When compressive strength is used as part of the basis for acceptance of fiber-reinforced concrete, make sets of at least two test specimens in accordance with the applicable requirements of Practices ASTM C31/C31M and C192/C192M and as specified in this section, or Test Methods C42/C42M or C1604/C1604M and condition and test in accordance with Test Methods EN 12390, C39/C39M, C42/ C42M, or C1604/C1604M. Acceptance shall not be based on compressive strength alone.

(d) The frequency of tests on hardened fiber-reinforced concrete shall be in accordance with the following requirements:

(i) Batch-Mixing: Tests shall be made with same frequency as in conventional concrete. Each test shall be made from a separate batch. On each day fiber-reinforced concrete is mixed, at least one test shall be made for each class of material.

(ii) When fibers are added, subject for approval of the Engineer, at the truck mixer the tests shall be made for each 20 m^3 or fraction thereof, or whenever significant changes have been made in the proportioning controls. On each day fiber-reinforced concrete is mixed, at least one test shall be made for each class of material.

(iii) For Shotcrete: Tests shall be made for each 38 m^3 placed using specimens sawed or cored from the structure or from corresponding test panels prepared in accordance with Practice ASTM C1604 and C 1140. On each day fiber-reinforced shotcrete is prepared; at least one test shall be made for each class of material.

6.8.4 Quality Control charts

1 The Contractor shall submit a continuous statistical analysis, on a monthly basis, for strength showing the potential strength of the concrete, variations in measured strength by determining the standard deviation (margin), batch-to-batch variations of the proportions and characteristics of the constituent materials in the concrete, the production, delivery, and handling process, and climatic conditions; and variations in the sampling, specimen preparation, curing, and testing procedures (within-test).

2 The Contractor shall provide in his analysis the mean strength, calculated standard deviation, the normal distribution of concrete strength and the frequency histogram. The Contractor shall draw the upper and lower lines for warning line (average mean strength $\pm$ 2 x standard deviation) and control line (average mean strength $\pm$ 3 x standard deviation)

3 The contractor shall use the methods, of computing standard deviation along with coefficient of variation and factors for computing within-test standard deviation from range, addressed in ACI 214

4 This recalculated margin, if adopted by the Engineer, becomes the current margin for the judgement of compliance with the specified characteristic strength of concrete

6.9 WORKS TEST CUBES

1 Test cubes shall be taken as specified from fresh mixed concrete which is being used in the Works and which has been prepared in the normal way.

2 Cubes shall be numbered sequentially and marked:

(a) Time, date and name of individual

(b) Section of work from which samples are taken

(c) Mix reference and delivery note number

(d) Name of technician

(e) and any other relevant information.

3 Tests for slump, as per EN 12350-2, and temperature shall be made and recorded whenever samples are taken.

4 The cube manufacture shall be in accordance with EN 12390-2.

5 When Self Compacting Concrete is used, the concrete specimens shall not be consolidated in moulds and it shall be placed in a single lift then levelled with minimum manipulation.

6 All samples shall be moulded at jobsite on a levelled surface area to within 20 mm per meter

7 Immediately after moulding and finishing, the specimens shall be stored for a period up to 48 h in a temperature range from 20 to 26˚C and in an environment preventing moisture loss from the specimens

8 Specimens shall not be transported or handled until at least 14 h after casting

9 Transportation time from site to laboratory for final curing and strength testing shall not exceed 4 hours. Specimens shall be protected from direct sun or rapid evaporation and placed on cushion layer to reduce vibration

6.10 REJECTION OF CONCRETE MIXES

6.10.1 Rejection of Concrete Mixes:

1 Concrete mixes shall be rejected if they fail to meet one or more requirements, which cannot be brought into compliance as related to any of the following:

(a) Improper class or grade of concrete
(b) Slump or temperature not within specified limits
(c) Oversized aggregate
(d) Maximum water-cementitious ratio is exceeded

2 Concrete shall not be rejected unless it has been visually inspected by the Engineer or representatives.

6.10.2 Unsatisfactory Concrete Works

1 Acceptance criteria of concrete strength shall be assessed as per Clause 6.8.2 (8g). Should any of the test results be unsatisfactory, the Engineer may order the work to be stopped pending his further instructions. Executed work for which test results are unsatisfactory shall be liable to rejection and if so advised the work shall be rebuilt at the Contractor's expense.

2 In the case of the 7-day works cube tests proving unsatisfactory, the work may be stopped liable to rejection pending the result of the 28-day test. If the test results fail to comply with the requirements, the work represented shall be immediately liable to rejection.

3 The cost of all such cuttings, preparation of specimens, transportation and testing, and of making good the portions of the structure affected shall be borne by the Contractor.

4 Regardless of satisfactory test cube results, any concrete work which, in the Engineer's opinion, is excessively honeycombed or in any other way is defective, shall be liable to rejection. Minor defects apparent on stripping the formwork must be made good at the Contractor's expense. No such repair work shall be carried out until after inspection by the Engineer and his acceptance of the proposed treatment has been given. Work which has not been previously inspected but which shows signs of such treatment shall be liable to rejection as defective work.

5 The cost of all delays on site due to faulty concrete work shall be met by the Contractor.

END OF PART