

SECTION 16
PLAIN AND REINFORCED CONCRETE

Contents

1601 GENERAL

1602 CONCRETE QUALITY

1603 MATERIALS AND TESTS

- 1603.1 General
- 1603.2 Cements
- 1603.3 Aggregates
- 1603.4 Water
- 1603.5 Reinforcement
- 1603.6 Tests on Concrete

1604 ALLOWABLE UNIT STRESSES

- 1604.1 Working Stresses

1605 MIXING AND PLACING

- 1605.1 Forms and Equipment
- 1605.2 Mixing of Concrete
- 1605.3 Conveying
- 1605.4 Depositing
- 1605.5 Curing
- 1605.6 Bonding
- 1605.7 Hot weather

1606 FORMS AND DETAILS OF CONSTRUCTION

- 1606.1 Design of Forms
- 1606.2 Removal of Forms
- 1606.3 Placing of Reinforcement
- 1606.4 Splices in Reinforcement
- 1606.5 Concrete Protection for Reinforcement
- 1606.6 Construction Joints
- 1606.7 Concrete Walls

1607 PRECAST CONCRETE FLOOR AND ROOF UNITS

- 1607.1 General
- 1607.2 Strength of Concrete
- 1607.3 Workmanship
- 1607.4 Identification and Marking
- 1607.5 Cutting of Holes

1607.6	Anchorage
1607.7	Bridging
1607.8	Connections
1607.9	Transportation, Storage and Erection

1608 PRESTRESSED CONCRETE

1608.1	General
1608.2	Design and Construction
1608.3	Handling and Installation

1609 FIBRE REINFORCED CONCRETE

1609.1	General
1609.2	Physical Properties
1609.3	Uses
1609.4	Manufacture

Table	16-1	Maximum Permissible Water-Cement Ratios for Concrete
-------	------	--

Table	16-2	Grading of Concrete
-------	------	---------------------

Table	16-3	Minimum Cover to be provided for Concrete
-------	------	---

Table	16-3(A)	Bar Designations
-------	---------	------------------

Table	16-4	Requirements for Special Exposure Conditions
-------	------	--

SECTION 16

PLAIN AND REINFORCED CONCRETE

1601 GENERAL

- (a) Reinforced and plain concrete shall be of materials, proportions, strength and consistency as set forth in this Section and shall be designed by methods admitting of rational analysis according to established principles of mechanics.
- (b) Standards of design and construction for reinforced concrete shall be in accordance with the provisions of the "Building Code Requirements for Reinforced Concrete, ACI 318.1 M-89", or in accordance with BS 5328 "Concrete", and for plain concrete in accordance with the "Building Code Requirements for Structural Plain Concrete ACI 322."
- (c) All members to be constructed of plain or reinforced concrete shall be designed to resist effectively the loads imposed in accordance with Section 12.

1602 CONCRETE QUALITY

- (a) Concrete mixes shall conform generally to those set out in Table 16-1. Where required by this Code, tests of concrete to determine suitable proportions of fine and coarse aggregates shall be carried out under the supervision of a qualified engineer. Where laboratory tests show that the required strengths may be obtained using higher water/cement ratios, the ratios given in Table 16-1 may be varied accordingly subject to the approval of the Director.
- (b) The Director may accept concrete mixed by volume provided the use of the concrete so mixed is limited to minor building works.
- (c) The Director may request that all plans submitted for approval or used for construction of a building or other works show clearly the class of concrete used in the design of all parts of the structure.
- (d) For grading of concrete mixes in accordance with BS 5328: "Concrete", see Table 16-2.

1603.1 General

- (a) The Director shall have the right to order testing of any materials used in concrete construction to determine if the materials are of the quality specified.
- (b) Tests of materials and of concrete shall be made in accordance with standards of the American Society for Testing and Materials. All tests are at the expense of the owner.
- (c) A complete record of tests of materials and of concrete placed shall be available for inspection by the Director during progress of work and for 2 years after completion of the project, and shall be preserved by the inspecting engineer or architect or owner (where no professionally qualified architect or engineer has been employed) for that purpose.

1603.2 Cements

- (a) Cement shall conform to one of the following specifications for Portland cement:
 - (1) "Specification for Portland Cement" ASTM C150.
 - (2) "Specification for Blended Hydraulic Cements" ASTM C595, excluding Types S and SA which are not intended as principal cementing constituents of structural concrete,or to any other equivalent standard approved by the Authority.
- (b) Cement used in the work shall correspond to that on which selection of concrete proportions was based.

1603.3 Aggregates

- (a) The use of aggregates for normal structural concrete shall be in accordance with Appendix F of CUBiC Part 2 Section 6 and with
 - i) ASTM C33 "Specification for Concrete Aggregates", or
 - ii) BS 882 Part 1 "Coarse and Fine Aggregates from Natural Sources".
- (b) Aggregates failing to meet the specifications listed in 1603.3 (a), but which have been shown by special tests or actual service to produce concrete of adequate strength and durability may be used where authorized by the Director.

- (c) Nominal maximum size of coarse aggregate shall be not larger than:
 - (1) $1/5$ the narrowest dimension between sides of forms nor
 - (2) $1/3$ the depth of slabs, nor
 - (3) $3/4$ the minimum clear spacing between individual pre-stressing tendons or ducts.

These limitations may be waived if, in the judgement of the Director, workability and methods of consolidation are such that concrete can be placed without honeycombs or voids.

1603.4 Water

- (a) Water used in mixing concrete shall be clean and free from injurious amounts of oils, acids, alkalis, salts, organic materials, or other substances that may be deleterious to concrete or reinforcement.
- (b) Mixing water for pre-stressed concrete or for concrete that will contain any aluminum embedments, including that portion of mixing water contributed in the form of free moisture on aggregates, shall not contain deleterious amount of chloride ions.
- (c) Non-potable water shall not be used in concrete unless the following are satisfied:
 - (1) Selection of concrete proportions shall be based on concrete mixes using water from the same source.
 - (2) Mortar test cubes made with non-potable mixing water shall have 7-day and 28-day strengths equal to at least 90 percent of strengths of similar specimens made with potable water. Strength test comparisons shall be made on mortars, identical except for the mixing water, prepared and tested in accordance with ASTM C109 - "Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-inch or 50 mm Cube Specimens)".

1603.5 Reinforcement

- (a) Deformed reinforcement shall conform to the relevant ASTM standard except as provided in ACI 318. Reinforcement conforming to other standards may be permitted by the Director provided that tests carried out by a laboratory approved by the Authority show that the reinforcement to be used is at least equal in quality to that specified in ACI 318.

- (b) Prestressing tendons shall conform to the relevant ASTM standard. Wire strands, and bars not specifically listed in ASTM A421, A416, or A722 may be used provided they conform to minimum requirements of these specifications and do not have properties that make them less satisfactory than those listed in ASTM A416, A421, or A722.
- (c) Reinforcement consisting of structural steel, steel pipe, or steel tubing may be used as specified in ACI 318.
- (d) All welding of reinforcement shall conform to the "Structural Welding Code-Reinforcing Steel, AWS D1.4" of the American Welding Society or equivalent standard approved by the Authority.

Reinforcement to be welded shall be indicated on the drawings and welding procedures to be used shall be specified. The Director may require the owner to provide a report (with appropriate tests) on the welding carried out.

Note: The designation of reinforcing bars is in conformance with US standards unless otherwise stated.

1603.6

Tests on concrete

- (a) The Director may require tests to be made during progress of the work, or may specify and set forth in writing such rules for requiring tests to be made by an approved agency as he may consider necessary to ensure compliance with the Code. Not fewer than three specimens shall be made for each standard test, nor fewer than one test for each 50 cubic yards of concrete or for each day's pour of concrete used at any job site, where pours may be less than 50 cubic yards. Tests shall be carried out in accordance with ASTM C172 or other approved standard. All tests will be carried out at the expense of the owner.
- (b) Three test cubes or cylinders should be made for each stage at which tests are required. The cube or cylinder strength should be calculated from the maximum load sustained by the cube or cylinder at failure. The appropriate strength requirement may be considered to be satisfied if none of the strengths of the three cubes or cylinders are below the specified strength or if the average strength of the cubes or cylinders is not less than the specified strength and the difference between the greatest and the least strengths is not more than 20 percent of that average.
- (c) In addition, where there is question as to the quality of the concrete in the structure, the Director may order load tests for that portion of the structure where the questionable concrete has been placed.

- (d) The maximum allowable slump of concrete shall be 4". This may be varied by the Director provided the design engineer can demonstrate that concrete of greater slump will produce an acceptable result.
- (e) No water shall be added at the job site to concrete delivered by truck as ready for use except under the control of a supervising engineer or other authority acceptable to the Director, and then only when slump tests are made and the concrete so delivered is found to have less than the maximum slump required.

1604 ALLOWABLE UNIT STRESSES

1604.1 Working Stresses

- (a) The allowable working stresses in concrete shall not exceed those set forth in ACI 318 (or equivalent standard) for the value of compressive strength of concrete used.

The normal minimum quality of structural concrete recognized by this Code shall be concrete having a design strength of 3,000 per sq.inch after 28 days based on 6" x 12" cylinder tests or 3,750 lbs per sq.in at 28 days based on 6" cubes.

- (b) The determination of the proportions of cement, aggregate, and water to attain strengths shall be made by one of the following methods:

Method 1 - Without preliminary tests

Where preliminary test data on the materials to be used in the concrete have not been obtained, the water-cement ratio for a given strength of concrete shall be based on those shown in Table 16-1. The designer and builder shall take every care to ensure that the water- cement ratio is kept at a minimum consistent with the type of aggregate being used. When tests have been carried out on the local aggregates, the relevant water- cement ratios shall be specified.

Method 2 - For combinations of materials previously evaluated or to be established by trial mixtures

Water-cement ratios greater than those shown in the Table 16-1 may be used provided that the relationship between strength and water-cement ratio for the materials to be used has been previously established by reliable test data and the resulting concrete satisfies the strength requirements.

- (d) When the structural design is based on a 28 day compressive strength in excess of 3,000 psi (by 6" x 12" cylinder test), proportioning, mixing and placing of concrete shall be under the supervision of a competent engineer, architect or concrete technician, approved by the Director.
- (e) Concrete that will be exposed to sulfate containing or other chemically aggressive solutions shall contain cements specially formulated to resist chemical action and be proportioned in accordance with the concrete proportions given in the Standards and Codes listed in Appendices A and B. Care shall be taken in using water containing hydrogen sulphide.

1605 MIXING AND PLACING

1605.1 Forms and Equipment

- (a) Before placing concrete, all equipment for mixing and transporting the concrete shall be cleaned, all debris removed from the spaces to be occupied by the concrete, forms shall be thoroughly wetted or oiled, masonry filler units that will be in contact with concrete shall be well drenched, and the reinforcement shall be thoroughly cleaned.
- (b) Water shall be removed from place of deposit before concrete is placed unless otherwise permitted by the Director.

1605.2 Mixing of Concrete

- (a) Unless otherwise authorized by the Director, the mixing of concrete shall be done in a batch mixer of approved type.
- (b) All concrete shall be mixed until there is a uniform distribution of the materials and shall be discharged completely before the mixer is recharged.
- (c) For job mixed concrete, the mixer shall be rotated at a speed recommended by the manufacturer and mixing shall be continued for at least 1-1/2 minutes after all materials are in the drum. For batches larger than one cubic yard, mixing time shall be increased 15 seconds for each additional cubic yard or fraction thereof.
- (d) Ready-mixed concrete shall be mixed and delivered in accordance with the requirements set forth in the Standards adopted in the Appendices to this Code.
- (e) Retempering concrete with the addition of water after the concrete has taken an initial set shall not be permitted.

- (f) No concrete shall be deposited in forms or used more than a maximum of 1-1/2 hours after the mixing of that particular batch has been commenced, or after water has been added to the batch. The Director has the right to reject all such concrete or order any such mobile equipment off the job site, if in his opinion, mixing has taken place longer than can be allowed to ensure the appropriate concrete strength. The Director may approve the use of a suitable concrete retarder to delay the setting action provided that the builder can prove by tests that the retarder used will not affect the strength of the concrete.
- (g) In cases where there is a delay in the completion of placing of concrete which is in progress, the builder must make suitable arrangements for completion of the pour or for the removal of the concrete already placed.

1605.3

Conveying

- (a) Concrete shall be conveyed from the mixer to the place of final deposit by methods which will prevent separation or loss of the materials.
- (b) Equipment for chuting, pumping and pneumatically conveying concrete shall be of such size and design as to ensure a practically continuous flow of concrete at the delivery end without separation of the materials.

1605.4

Depositing

- (a) Concrete shall be deposited as nearly as practicable in its final position to avoid segregation due to rehandling or flowing. The concreting shall be carried on at such a rate that the concrete is at all times plastic and flows readily into the spaces between the bars. No concrete that has been contaminated by foreign materials shall be deposited in the structure.
- (b) When concreting is once started, it shall be carried on as a continuous operation until the placing of the panel or section is completed.
- (c) All concrete shall be thoroughly consolidated by suitable means during placement, and shall be thoroughly worked around the reinforcement and embedded fixtures and into the corners of the forms. Where concrete is placed in columns or walls, the placing shall be so conducted that the concrete will not be placed in lifts greater than 8 feet. Separate lifts shall be thoroughly compacted.
- d) Vibrators may be used to aid in the placement of the concrete, provided that the forms are designed to withstand their action, and that the vibrators do not touch the reinforcement. Vibrators should not be used to transport concrete within the forms.

- (e) Where conditions make consolidation difficult or where reinforcement is congested, the Director upon application of the builder, may approve alternative methods of placing of the concrete or redesigning the steel in the member affected.
- (f) Special care shall be taken in depositing concrete from heights greater than 4 feet to avoid segregation or separation.

1605.5 Curing

In all concrete structures, concrete made with normal Portland cement shall be maintained above 10 degrees C. and in a moist condition for at least the first seven days after placing. High-early -strength concrete shall be so maintained for at least the first three days. Other curing periods or methods of curing may be used if the specified strengths are obtained. (See CUBiC Part 2 Section 6 Article 5.5).

1605.6 Bonding

Before new concrete is deposited on or against concrete which has set, the forms shall be re-tightened, the surface of the set concrete shall be cleaned of all foreign matter and washed before the new concrete is placed.

1605.7 Hot Weather

During hot weather (temperature in excess of 85 degrees F.), steps shall be taken to reduce concrete temperature and water evaporation by proper attention to ingredients, production methods, handling, placing, protection and curing.

1606 FORMS AND DETAILS OF CONSTRUCTION

1606.1 Design of Forms

- (a) Forms shall conform to the shape, lines and dimensions of the members as called for on the plans, and shall be substantial and sufficiently tight to prevent leakage of mortar. Forms shall be properly braced or tied together so as to maintain position and shape. Temporary openings at the bottom of columns shall be provided to facilitate cleaning and inspection before depositing concrete.

When the concrete has attained sufficient strength, forms shall be removed from at least two faces of all reinforced members, other than where placed in contact with the soil.

- (b) Design of formwork shall include consideration of the following factors:
 - (1) Rate and method of placing concrete.

- (2) Loads, including live, dead, lateral and impact.
- (3) Selection of materials and stresses.
- (4) Deflection, camber, eccentricity and uplift.
- (5) Horizontal and diagonal shear bracing.
- (6) Splices.
- (7) Cross grain compression.
- (8) Loads on ground or on previously placed structure.

1606.2 Removal of Forms

The removal of forms shall be carried out in such a manner as to ensure the complete safety of the structure. Vertical forms may be removed in 24 hours, provided that the concrete has hardened sufficiently so that it is not injured. Bottom forms and shoring for slabs, beams and girders shall not be removed in less than 14 days. Where tests indicate that the concrete has attained sufficient strength to safely support itself and any imposed loads in less time, adjustments in the above waiting periods may be approved by the Director in conformance with the results obtained.

1606.3 Placing of Reinforcement

- a) Skeletal reinforcement and welded wire fabric shall be accurately placed and adequately secured in position by concrete or metal chairs or spacers, or by other acceptable methods. The minimum clear distance between parallel bars, except in columns, shall be equal to the nominal diameter of the bars. In no case shall the clear distance between bars be less than one inch, nor less than one and one-third times the maximum size of the coarse aggregate.
- b) When reinforcement in beams or girders is placed in two or more layers, the clear distance between layers shall not be less than one inch nor less than the diameter of the bars, and the bars in the upper layers shall be placed directly above those in the bottom layer.
- c) Groups of parallel reinforcing bars bundled in contact to act as a unit are permitted but shall be limited to four bars in any one unit. Bars larger than #11 can not be bundled in beams. Individual bars within a bundle terminated within the span of flexural members shall terminate at different points with stagger at least 40 bar diameters. Bundled bars shall be enclosed within stirrups or ties.

1606.4 Splices in Reinforcement

In slabs, beams, and girders, splices in reinforcement at points of maximum stress shall be welded, lapped or otherwise fully developed, but in any case, shall transfer the entire stress from the bar without exceeding the allowable bond and shear stresses. The minimum overlap for a lapped splice shall be calculated in accordance with ACI 318-55, but in no case shall the overlap be less than 35 bar diameters. The clear distance between bars shall also apply to clear distance from a contact splice and adjacent splices or bars.

1606.5 Concrete Protection for Reinforcement (See Table 16-3)

- (a) The reinforcement of footings and other principal structural members in which the concrete is deposited against the ground shall have not less than 3 inches of concrete between it and the ground contact surface. If concrete surfaces after removal of the forms are to be exposed to the weather or be in contact with the ground, the reinforcement shall be protected with not less than 2 inches of concrete.
- (b) The concrete protective covering for reinforcement at surfaces not exposed directly to the ground or weather shall be not less than 1 inch for slabs and walls; and not less than 1-1/2 inches for beams, girders and columns. In concrete ribbed or joist floors in which the clear distance between ribs or joists is not more than thirty inches, the protection of reinforcement shall be at least 1 inch.
- (c) Exposed reinforcement bars intended for bonding with future extensions shall be protected from corrosion by concrete or other adequate covering.
- (d) The above protective coverings are minimums but protection shall not be less than elsewhere set forth for required fire resistive ratings and for insurance against corrosion.
- (e) In extremely corrosive atmospheres, such as in locations near the sea, or other severe exposures, the amount of protection (concrete cover) shall be suitably increased but not so much as to allow excessive crack widths at the surface.

1606.6 Construction Joints

- (a) Joints not indicated on the plans shall be so made and located as to least impair the strength of the structure. Where a joint is to be made, the surface of the concrete shall be thoroughly cleaned and all laitance removed. Vertical joints shall be thoroughly wetted before placing of new concrete.
- (b) A delay of at least one day must occur in columns or walls before concreting beams, girders, or slabs supported thereon.

Beams, girders, brackets, column capitals, and haunches shall be considered as part of the floor system and shall be placed monolithically therewith.

- (c) Construction joints shall be located in areas of minimum shear. Provision shall be made for transfer of shear and other forces through the construction joint.

1606.7

Concrete Walls

- a) The design of concrete walls subject to axial loads with or without flexure shall be carried out in accordance with Part 2 Section 6 Subsection 14 of CUBiC.
- b) The minimum vertical and horizontal reinforcement required for walls shall be in accordance with Part 2 Section 6 Subsection 14.3 of CUBiC, unless a greater amount of reinforcement is required for shear or other loads.
- c) The minimum ratio of the area of vertical reinforcement to the gross concrete the area shall be :
 - i) 0.0012 for deformed bars not larger than No.15 with a specified yield strength of not less than 400 MPa, or
 - ii) 0.0015 for other deformed bars, or
 - iii) 0.0012 for welded wire fabric not larger than W31 or D31
- d) The minimum ratio of the area of horizontal reinforcement area to the gross concrete are shall be:
 - i) 0.0020 for deformed bars no larger than No 15 with a specified yield strength not less than 400 MPa, or
 - ii) 0.0025 for other deformed bars or
 - iii) 0.0020 for welded wire fabric not larger than W31 or D31.
- e) Vertical and horizontal reinforcement shall not be spaced further than three times the wall thickness, nor 500 mm. (20 Inches).
- f) In addition to the minium reinforcement required by 1606.7 d) and e), not less than two No. 4 bars shall be provided around all window and door openings. Such bars shall be extended to develop the bar beyond the corners of the openings but not less than 24 inches.

1607.1 General

- (a) Precast concrete units shall comply with the minimum requirements set forth in this Section, and the Standards set forth in the Appendices.
- (b) All precast structural items shall be designed by an engineer approved by the Authority.
- (c) Only the material cast monolithically with the units at the time of manufacture shall be used in computing stresses unless adequate and approved mechanical shear transfer is provided.
- (d) The Director may require tests to be made by an approved testing laboratory as he may consider necessary to ensure compliance with this Code or uniformity of the products produced. The quantity of tests shall be based on consideration of safety or volume of output.
- (e) The Director shall have free access to the plant of any producer at all hours of normal operation, and failure to permit such access shall be cause for revocation of approval.
- (f) Failure of any product to satisfy in every respect the quality prescribed, or failure to conform with plans and specifications, shall be cause for rejection of the products.

1607.2 Strength of Concrete

Concrete for precast structural units made of crushed stone or other heavy aggregate shall have a compressive strength of not less than 3,000 psi at 28 days based on standard 6" cylinder test.

1607.3 Workmanship

- (a) The mix, the gradation of the aggregate and the workability shall be such as to ensure complete filling of the form and continuous intimate bond between the concrete and all steel.
- (b) The use of precast structural units not complying with the relevant Standards and Codes listed in the Appendices, or having visible cracks, honeycomb, exposed reinforcing except at ends or, with a compressive section more than one-eighth inch less than specified dimension shall not be permitted.

1607.4 Identification and Marking

All joists, beams and girders, and other units shall show some mark plainly indicating the top of the unit and its location and orientation in the structure. Identification marks shall be reproduced from the placing

plans. This mark or symbol shall also indicate the manufacturer, the date of the manufacture and the lengths, size and type of reinforcing.

1607.5 Cutting of Holes

No openings not provided for in the structural design shall be made on the job without the specific approval of the engineer and the Director and in accordance with the engineer' written detailed instructions covering such work.

1607.6 Anchorage

Anchorage of all precast concrete units shall be designed based on rational analysis to transmit loads and other forces to the structural frame.

1607.7 Bridging

Joists shall be secured against lateral displacement by cast-in-place bridging, and such bridging shall be spaced not to exceed 32 times the width of the compression flange of the joist; except that for roof systems, cast-in-place Portland cement concrete slabs embedding the top flanges not less than 1/2 inch, or steel decks which are welded, shall be accepted in lieu of bridging.

1607.8 Connections

- (a) All joints and connections shall perform their function at all stages of loading without over-stress and with proper safety factors against failure due to overload.
- (b) Loading conditions to be considered in the design of joints and connections are: service loads, including wind and earthquake forces, volume changes due to shrinkage, creep, and temperature change, erection loads, and loading encountered in stripping forms, shoring and removal of shores, storage and transportation of members.

1607.9 Transportation, Storage and Erection

- (a) Units shall be so stored, transported, and placed that they will not be overstressed or damaged.
- (b) Precast concrete units shall be adequately braced and supported during erection to ensure proper alignment and safety and such bracing or support shall be maintained until there are adequate permanent connections.

1608.1**General**

- (a) The term "prestressed concrete" refers to pretensioned concrete in which the reinforcing is tensioned before hardening of the concrete; or to post-tensioned concrete in which the reinforcing is tensioned after hardening of the concrete or combinations of both pre-tensioning and post-tensioning.
- (b) All prestressed structural items shall be designed by an engineer approved by the Authority. Openings not provided for in the structural design shall not be made on the job without the specific approval of the engineer and the Director
- (c) Allowable stresses, temporary and at design loads, shall not exceed the allowable stresses set forth in the relevant Standards and Codes of Practice listed in Appendices A and B. Stresses and ultimate strength shall be investigated at service conditions and at all load stages that may be critical during the life of the structure from the time prestress is first applied.
- (d) The Director may require tests to be made by an approved testing laboratory as he may consider necessary to ensure compliance with these Standards or uniformity of the product.
- (e) The Director shall have free access to the plant of any producer at all hours of normal operation, and failure to permit such access shall be cause for revocation of approval.
- (f) Failure of any product to satisfy the quality prescribed or failure to conform with plans and specifications shall be cause for rejection of the product.

1608.2**Design and Construction**

- (a) Deflection under live load shall not exceed $L/240$ and where plaster ceilings are to be applied shall not exceed $L/360$, where L = the span length of the member.
- (b) Calcium chloride shall not be used in concrete for prestressed members.

1608.3**Handling and Installation**

Prestressed members must be maintained in an upright position at all times and must be picked up from points as shown on the approved plans or as approved by the engineer and the Director.

(Note: Disregard of this requirement may lead to collapse of the member).

1609.1

General

The development of reinforced concrete using fibre glass materials has led to the construction of structural panels and other primary non load-bearing members. The principal ingredients of glass reinforced cement (GRC) are ordinary Portland cement., silica sand and water, mixed with alkali resistant glass fibres to produce the inorganic GRC composite. Glass fibres constitute 5% by weight.

The advantage of GRC is its ability to produce elements which are much thinner and lighter than can be made with ordinary concrete reinforced with steel. GRC elements of 1/2" in thickness are possible while with steel reinforced concrete, the thickness of any slab must be at least 1-1/2" to provide cover for the reinforcement. In the OECS, where the cover should be at least 1" for exposed elements, the minimum thickness of a slab will be 2-1/2".

1609.2

Physical Properties

Some of the physical properties of typical spray de-watered GRC with a density of 2.0 tonnes per sq.m. are:

Property	At completion of cure
Impact strength	15 -20 Nmm/mm ²
Compressive strength	60 - 100 N/mm ²
Young's Modulus	20 - 25 KN/mm ²
Bending - elastic limit	14 - 17 N/mm ²
Bending - ultimate strength	35 - 40 N/mm ²
Tension - elastic limit	9 - 10 N/mm ²
Tension - ultimate strength	14 - 17 N/mm ²

Note: 1N = 0.224809 lbf.

$$\text{N/mm}^2 = 0.00689476 \text{ lb/in}^2 \times 10$$

1609.3

Uses

GRC technology has been used in the production of semi-structural units and complex shapes such as cladding panels, roofing, fire doors and partitions, bus shelters, storage tanks and other units such as corrugated sheeting which can be produced by the spray method.

Other smaller units are constructed by premix GRC such as sewer pipes, manhole covers, etc.

1609.4 Manufacture

GRC members are manufactured under licence. Information on the manufacture, properties and uses of GRC can be obtained from the Building Research Establishment, Wallingford, England.

Table 16-1

**Maximum Permissible Water Cement Ratios (1) for Concrete
(Without Preliminary Tests)**

Maximum Permissible Water Cement Ratio - Non Air Entrained Concrete (2)			
Specified Compressive strength at 28 days, (psi - 6" cube test)	Specified Compressive Strength at 28 days, (psi - 6" x 12" cylinder)	U.S. gals per 94 lb bag of cement	Absolute ratio by weight
3,125	2,500	7-1/4	0.67
3,750	3,000	6-1/2	0.58
4,375	3,500	5-3/4	0.51
5,000	4,000	5	0.44

- Notes: 1) The minimum cement content shall be not less than five bags per cubic yard (a bag weighing not less than 94 pounds) unless the mix is designed specifically for the project.
- 2) Including free surface moisture on aggregates.
- 3) Results shown in this table are based on the use of aggregates with equivalent specification of BS 882 Part 1. For local limestone aggregates tests are required to arrive at the appropriate water cement ratio.

Table 16-2

Grading of Concrete Mixes in accordance with BS 5328

Grade	Approx. minimum compressive strength at 28 days (psi)
ST1	1,090
ST2	1,490
ST3	2,175
ST4	2,900
ST5	3,625

Table 16-3

Minimum Cover to be Provided to Concrete

A. Cast in Place Concrete (Non-prestressed)	
Description	Minimum Cover (ins)
Concrete cast against and permanently exposed to earth	3
Concrete expose Cd to earth and weather:	2
Concrete not exposed to weather or in contact with the ground:	
Slabs, Walls, Joists	1-1/2
Beams, Columns	1-1/2
Shells, Folded plate members	3/4

Table 16-3 (Cont'd)

Minimum Cover to be Provided to Concrete

B. Precast Concrete Manufactured under Plant Control Conditions	
Description	Minimum Cover (ins)
Concrete exposed to earth or weather:	
<u>Wall Panels:</u>	
No 14 and No 18 bars*	1-1/2
No 11 bar and smaller	1
<u>Other members:</u>	
No 14 and No 18 bars	2
No 6 through No 35 bars	1-1/2
No 5 bar, W31 or D31 wire and smaller	1-1/2
Concrete not exposed to weather or in contact with the ground:	
<u>Slabs, Walls, Joists:</u>	
No 14 and No 18 bars	1-1/4
No 11 bar and smaller	3/4
<u>Beams, Columns:</u>	
Primary Reinforcement:	Bar diameter, but not less than 3/4 and not more than 1-3/4
Ties, Stirrups, Spirals	1/2
<u>Shells, Folded Plate members:</u>	
No 6 bar and larger	3/4
No 5 bar, W31 or D31 wire and smaller	1/2

Note: See Table 16-3(A) for equivalent SI bar designations.

Table 16-3 (Cont'd)

Minium Cover to be Provided to Concrete

C. Prestressed Concrete	
Description	Minimum Cover (ins)
Concrete cast against and permanently exposed to earth	3
Concrete exposed to earth or weather	
Wall Panels, Slabs, Joists	1-1/4
Other Members	1-1/2
Concrete not exposed to weather or in contact with the ground	
Slabs, Walls, Joists	1
Beams, Columns	1-1/2
Primary Reinforcement	1-1/2
Ties, Stirrups, Spirals	1
Shells, Folded Plate Members	1/2
No 5 Bar, W31 or D31 Wire and Smaller	1/2
Other Reinforcement	Bar diameter but not less than 1

Note: See Table 16-3A for bar designations

Table 16-3(A)

Bar Designations

SI Units		US Standard Units	
Bar Designation	Diameter (mm)	Bar Designation	Diameter (ins)
10	11.3	3	0.375
15	16.0	4	0.500
20	19.5	5	0.625
25	25.2	6	0.750
30	29.9	7	0.875
35	35.7	8	1.000
45	43.7	9	1.128
55	56.4	10	1.270
		11	1.410
		14	1.693
		18	2.257

Table 16-4

Requirements for Special Exposure Conditions

Exposure Condition	Maximum Water-cement ratio normal density aggregate concrete	Minimum specified compressive strength, low density aggregate (Mpa)
Concrete intended to be water -tight:		
a) Concrete exposed to fresh water	0.50	25
b) Concrete exposed to seawater	0.45	30
For corrosion protection for reinforced concrete exposed to brackish water, seawater, or spray from these sources	0.40	33

- * If minimum concrete cover required by Table 16-3 is increased by 10 mm, water-cement ratio may be increased to 0.45 for normal density concrete, or specified compressive strength reduced to 30 MPa for low density concrete.

Note: 1 Megapascal (MPa) equals 145.038 lbs force per sq.in