CONSTRUCTION STANDARD

FOR

CONCRETE STRUCTURES

CONTENTS :

PAGE No.

1. SCOPE

This Construction Standard covers the minimum technical requirements for construction of plain, reinforced, prestressed, precast and composite concrete elements and structures.

It defines methods and tests for material selection and admixtures. Presents guidelines for prevention of concrete deterioration and steel corrosion from constructional view point. It also includes methods for sampling, mixing, conveying, placing, curing, hot and cold weather concreting.

2. REFERENCES

The following standards and publications are referred to and to the extent specified form a part of this Standard:

AASHTO (AMERICAN ASSOCIATION OF STATE HIGHWAYS AND TRANSPORTATION ORGANIZATION)

AASHTO T260-84	"Method of Sampling and Testing for Total Chloride Ion in Concrete and Concrete Raw Materials"

ACI (AMERICAN CONCRETE INSTITUTE)

ACI 318 M-89	"Building Code Requirements for Reinforced Concrete"
ACI 347-78(84)	"Recommended Practice for Concrete Formwork"

ASTM (AMERICAN SOCIETY FOR TESTING AND MATERIALS)

For General List of Standards Used in this Standard Refer to Section 3.8 of ACI Code 318M-89.

AWS (AMERICAN WELDING SOCIETY)

AWS D1.4-79	"Structural Welding Code-Reinforcing Steel"

BSI (BRITISH STANDARDS INSTITUTION)

BS 8110: 1985 Part 1	"Structural Use of Concrete"

PCA (PORTLAND CEMENT ASSOCIATION)

"Design and Control of Concrete Mixtures", 1979

3. DEFINITIONS AND TERMINOLOGY

For general definition of terms used in this Standard refer to Chapter 2 of ACI 318 M-89.

4. NOTATIONS & SYMBOLS

For complete listing of Notations refer to Appendix B of ACI 318 M-89. The following symbols and notations are a selection of frequently used ones in this Standard.

d_b = Nominal diameter of bar, wire, or prestressing strand, mm
f_c' = Specified compressive strength of concrete, MPa (kg/cm²).
f_{ct} = Average splitting tensile strength of low-density aggregate concrete, MPa (kg/cm²).

f_{cr} = Required average compressive strength of concrete used as the basis for selection of concrete proportions, MPa (kg/cm²).

5. UNITS

This Standard is based on International System of Units (SI), except where otherwise specified.

6. Materials

6.1 Cements

6.1.1 Cement shall conform to the following specifications for Portland cement:

a) "Standard Specification for Portland Cement" (ASTM C 150-86).

6.1.2 Cement used in the work shall correspond to that on which selection of concrete proportions was based.

6.1.3 Fly Ash or other pozzolans shall conform to ASTM C 618-85 "Standard Specification for Fly Ash and Raw or Calcined Natural Pozzolan for Use as Mineral Admixture in Portland Cement Concrete".

6.2 Aggregates

6.2.1 Concrete aggregates shall conform to one of the following specifications:

a) "Standard Specification for Concrete Aggregates" (ASTM C 33-86).
b) "Standard Specification for Lightweight Aggregates for Structural Concrete" (ASTM C 330-87).
c) Gradation of fine aggregates and coarse aggregates shall be within the limit mentioned in Tables 1 and 2.

Exception: Aggregates which have been shown by special test or actual service to produce concrete of adequate strength and durability and approved by the AR*.

*** AR Authorized Representative of the Owner**

TABLE 1 - GRADING REQUIREMENTS FOR FINE AGGREGATES

SIEVE (SPECIFICATION E 11)	PERCENT PASSING
3/8 in (9.5 mm)	100
No. 4 (4.75 mm)	95 to 100
No. 8 (2.36 mm)	80 to 100
No. 16 (1.18 mm)	50 to 85
No. 30 (600 µm)	25 to 60
No. 50 (300 µm)	10 to 30
No. 100 (150 µm)	2 to 10

TABLE 2 - GRADING REQUIREMENTS FOR COARSE AGGREGATES

Number	Nominal Size	Amounts Finer than Each Laboratory Sieve (Square-Openings), Weight Percent												
	(Sieves with Square Openings)	4 in (100 mm)	3½ in (90 mm)	3 in (75mm)	2½ in (63 mm)	2 in (50 mm)	1½ in (37.5 mm)	1 in (25.0 mm)	¾ in (19.0 mm)	½ in (12.5 mm)	⅜ in (9.5 mm)	No.4 (4.75 mm)	No.8 (2.36 mm)	No.16 (1.18 mm)
1	3½ to 1½ in (90 to 37.5 mm)	100	90 to 100	...	25 to 60	...	0 to 15	...	0 to 5	...	...	...	...	...
2	2½ to 1½ in (63 to 37.5 mm)	...	...	100	90 to 100	35 to 70	0 to 15	...	0 to 5	...	...	...	...	...
3	2 to 1 in (50 to 25.0 mm)	...	...	...	100	90 to 100	35 to 70	0 to 15	...	0 to 5	...	...	...	...
357	2 in to No.4 (50 to 4.75 mm	...	...	...	100	90 to 100	...	35 to 70	...	10 to 30	...	0 to 5	...	...
4	1½ to ¾ in (37.5 to 4.75 mm)	...	...	...	...	100	90 to 100	20 to 55	0 to 15	...	0 to 5	...	...	...
467	1½ in to No.4 (37.5 to 4.75 mm)	...	...	...	...	100	90 to 100	...	35 to 70	...	10 to 30	0 to 5	...	...
5	1 to ½ in (25.0 to 12.5 mm)	...	...	...	...	...	100	90 to 100	20 to 55	0 to 10	0 to 5	...	...	...
56	1 to ⅜ in (25.0 to 9.5 mm)	...	...	...	...	...	100	90 to 100	40 to 85	10 to 40	0 to 15	0 to 5	...	...
57	1 in to No.4 (25.0 to 4.75 mm)	...	...	...	...	...	100	95 to 100	...	25 to 60	...	0 to 10	0 to 5	...
6	¾ to ⅜ in (19.0 to 9.5 mm)	...	...	...	...	...	...	100	90 to 100	20 to 55	0 to 15	0 to 5	...	...
67	¾ in to No.4 (19.0 to 4.75 mm)	...	...	...	...	...	...	100	90 to 100	...	20 to 55	0 to 10	0 to 5	...
7	½ in to No.4 (12.5 to 4.75 mm)	...	...		...	...	...	...	100	90 to 100	40 to 70	0 to 15	0 to 5	...
8	⅜ in to No.8 (9.5 to 2.36 mm)	...	...	...	...	...	...	...	...	100	85 to 100	10 to 30	0 to 10	0 to 5

6.2.2 Nominal maximum size of coarse aggregate shall be not larger than:

a) 1/5 the narrowest dimension between sides of forms, nor;

b) 1/3 the depth of slabs, nor;

c) ¾ the minimum clear spacing between individual reinforcing bars or wires, bundles of bars, or prestressing tendons or ducts.

These limitations shall not apply if, in the judgment of the AR, workability and methods of consolidation are such that concrete can be placed without honeycomb or voids.

6.3 Water

6.3.1 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.

6.3.2 Mixing water for prestressed concrete or for concrete that will contain aluminum embedments, including that portion of mixing water contributed in the form of free moisture on aggregates, shall not contain deleterious amounts of chloride ion.

6.3.3 Nonpotable water shall not be used in concrete unless the following are satisfied:

a) Selection of concrete proportions shall be based on concrete mixes using water from the same source.

b) Mortar test cubes made with nonpotable 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 comparison shall be made on mortars, identical except for the mixing water, prepared and tested in accordance with "Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 50-mm Cube Specimens)" (ASTM C 109-86).

c) Sea water shall not be used as mixing water.

6.4 Metal Reinforcement

For general description and method of use of concrete reinforcement refer to Section 3.5 of ACI-318M-89.

6.5 Admixtures and Additives

6.5.1 An admixture shall be capable of maintaining essentially the same composition and performance throughout the work as the product used in establishing concrete proportions in accordance with Clause 7.2.

6.5.2 Aditives to be used in concrete shall be subject to written approval of AR.

6.6 Storage of Materials

6.6.1 Cement and aggregates shall be stored in such manner as to prevent deterioration or intrusion of foreign matter.

6.6.2 Any material that has deteriorated or has been contaminated shall not be used for concrete.

6.6.3 Tests of reinforcing materials and of concrete shall be made in accordance with standards listed in Clause 3.8 of ACI 318 M-89.

7. DURABILITY REQUIREMENTS

7.1 Freezing and Thawing Exposures

7.1.1 Normal density and low-density concrete exposed to freezing and thawing or deicer chemicals shall be air entrained with air content indicated in Table 3. Tolerance on air content as delivered shall be ±1.5 percent. For specified compressive strength f_c greater than 35 MPa, air content indicated in Table 3 may be reduced 1 percent.

TABLE 3 - TOTAL AIR CONTENT FOR FROST - RESISTANT CONCRETE

NOMINAL MAXIMUM AGGREGATE SIZE, mm 1)	AIR CONTENT, PERCENT	
	SEVERE EXPOSURE	MODERATE EXPOSURE
9.5	7-12	6
12.5	7	5-½
19.0	6	5
25.0	6	4-½
37.5	5-½	4-½
50 2)	5	4
75 2)	4-½	3-½

1) See ASTM C 33 for tolerances on oversize for various nominal maximum size designations.

2) These air contents apply to total mix, as for the preceding aggregate sizes. When testing these concretes, however, aggegate larger than 37.5 mm is removed by hand-picking or sieving and air content is determined on the minus 37.5 mm fraction of mix, (Tolerance on air content as delivered applies to this value) Air content of total mix is computed from value determined on the minus 37.5 mm fraction.

7.1.2 Concrete that will be subject to freezing and thawing in a moist condition, intended to have low permeability to water or be exposed to deicing salts, brackish water, sea water, or spray from these sources shall conform to the requirements of Table 4.

7.1.3 When reinforced concrete will be exposed to deicing salts, brackish water, sea water, or spray from these sources, requirements of Table 4 for water-cement ratio or concrete strength and minimum concrete cover requirements of Clause 13.7 shall be satisfied.

TABLE 4 - REQUIREMENTS FOR SPECIAL EXPOSURE CONDITIONS

EXPOSURE CONDITION	MAXIMUM WATER-CEMENT RATIO, NORMAL DENSITY AGGREGATE CONCRETE	MINIMUM f_c', LOW-DENSITY AGGREGATE CONCRETE
Concrete intended to have low permeability when exposed to water	0.50	25
Concrete exposed to freezing and thawing in a moist condition	0.45	30
For corrosion protection for reinforced concrete exposed to deicing salts, brackish water, seawater or spray from these sources	0.40*	30*
Watertight concrete		
In fresh water	0.50	25
In seawater	0.45	30
Frost-resistant concrete		
Thin sections; any section with less than 50 mm" cover over reinforcement and any concrete exposed to deicing salts	0.45	30
All other structures	0.50	25
Exposure to sulfates		
Moderate	0.50	25
Severe	0.45	30
Pacing concrete under water	Not less than 386 kg of cement per cubic meter	
Floors on grade	Select water-cement ratio for strength, plus minimum cement requirements, Table 8	

Note:

If minimum concrete cover required by Clause 13.7 is increased by l0 mm, water-cement ratio may be increased to 0.45 for normal density concrete, or f'_c reduced to 30 MPa for low-density concrete.

7.1.4 For corrosion protection, maximum water soluble chloride ion concentrations in hardened concrete at ages from 28 to 42 days contributed from the ingredients including water, aggregates, cementitious materials and admixtures shall not exceed the limits of Table 5 When testing is performed to determine water soluble chloride ion content, test procedures shall conform to AASHTO T 260-84.

TABLE 5 - MAXIMUM CHLORIDE ION CONTENT FOR CORROSION PROTECTION

TYPE OF MEMBER	MAXIMUM WATER SOLUBLE CHLORIDE ION (Cl^-) IN CONCRETE, PERCENT BY MASS OF CEMENT
Prestressed concrete	0.06
Reinforced concrete exposed to chloride in service	0.15
Reinforced concrete that will be dry or protected from moisture in service	1.00
Other reinforced concrete construction	0.30

7.1.4.1 Concrete to be exposed to sulfate-containing solutions or soils shall conform to requirements of Table 6, or be made with a cement that provides sulfate resistance and used in concrete with maximum water-cement ratio or minimum compressive strength from Table 6.

7.1.4.2 Calcium chloride as an admixture shall not be used in concrete to be exposed to severe or very severe sulfate-containing solutions, as defined in Table 6.

TABLE 6 - REQUIREMENTS FOR CONCRETE EXPOSED TO SULFATE-CONTAINING SOLUTIONS

SULFATE EXPOSURE	WATER SOLUBLE SULFATE (SO_4) IN SOIL, PERCENT BY MASS	SULFATE (SO_4) IN WATER ppm	CEMENT TYPE	NORMAL DENSITY AGGREGATE CONCRETE	LOW DENSITY AGGREGATE CONCRETE
				MAXIMUM WATER-CEMENT RATIO, BY MASS 1)	MINIMUM COMPRESSIVE STRENGTH f_c' MPa 1)
Negligible	0.00-0.10	0 - 150	—	—	—
Moderate 2)	0.10-0.20	150 - 1500	II and I	0.50	25
Severe	0.20-2.00	1550 - 10000	V	0.45	30
Very severe	Over 2.00	Over 10000	V plus Pozzolan 3)	0.45	30

1) A lower water-cement ratio or higher strength may be required for low permeability or for protection against corrosion of embedded items or freezing and thawing.

2) Seawater.

3) Pozzolan that has been determined by test or service record to improve sulfate resistance when used in concrete containing Type V cement.

7.1.4.3 Air-entraining admixtures shall conform to ASTM C 260-86, "Standard Specification for Air-Entraining Admixtures for Concrete".

7.1.4.4 Water-reducing admixtures, retarding admixtures, accelerating admixtures; water reducing and retarding admixtures, and water reducing and accelerating admixtures shall conform to ASTM C 494-86, "Standard Specification for Chemical Admixtures for Concrete".

7.1.4.5 Fly Ash or other pozzolans used as admixtures shall conform to ASTM C 618-85, "Standard Specification for Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete."

7.1.4.6 Ground granulated blast-furnace slag used as an admixture shall conform to "Standard Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars" (ASTM C 989-87a).

7.1.4.7 The types of admixtures suitable for use in concrete to obtain the desired effect are listed in Table 6.

TABLE 7- ADMIXTURES BY CLASSIFICATION

	TYPE OF ADMIXTURE	MATERIAL
Improve durability	Air entraining (ASTM C260)	Salts of wood resins Some synthetic detergents Salts of sulfonated lignin Salts of petroleum acids Salts of proteinaceous material Fatty and resinous acids and their salts Alkylbenzene sulfonates
Reduce water required for given consistency	Water reducer (ASTM C494, Type A)	Lignosulfonates Hydroxylated carboxylic acids (Also tend to retard set so accelerator is added)
Retard setting time	Retarder (ASTM C494, Type B)	Lignin Borax Sugars Tartaric acid and salts
Accelerate setting and earlystrength development	Accelerator (ASTM C494, Type C)	Calcium chloride (ASTM D98) Triethanolamine
Reduce water and retard set	Water reducer and retarder (ASTM C494, Type D)	(See water reducer, Type A, above)
Reduce water and accelerate set	Water reducer and accelerator (ASTM C494, Type E)	(See water reducer, Type A, above. More accelerator is added)
Improve workability and plasticity	Pozzolan (ASTM C618)	Natural pozzolans (Class N) Fly ash (Class F and G) Other materials (Class S)
Cause expansion on setting	Gas former	Aluminum power Resin soap and vegetable or animal glue Saponin Hydrolized protein
Decrease permeability	Dampproofing and waterproofing agents	Stearate of calcium, aluminum, ammonium, or butyl Petroleum greases or oils Soluble chlorides
Improve pumpability Decrease air content	Pumping aids Air detrainer	Pozzolans Organic polymers Tributyl phosphate
High flow	Superplasticizers	Sulfonated melamine formaldehyde condensates Sulfonated naphthalene formaldehyde condensates

7.1.5 For placeability, finishability, abrasion resistance, and durability in flatwork, with regard to aggregate size, the quantity of cement to be used should be not less than shown in Table 8.

TABLE 8 - MINIMUM CEMENT REQUIREMENTS FOR CONCRETE USED IN FLATWORK

MAXIMUM SIZE OF AGGREGATE, mm	CEMENT, kg/m^3
28	282
25	312
19	324
12.5	354
9.5	366

7.1.6 The minimum cement content of concrete mixtures exposed to freezing and thawing in the presence of deicing chemicals shall be 252 kg of cement meeting ASTM C 150 or C 595 per m^3 of concrete.

7.1.7 The water-cement ratio required in Tables 4 and 7 shall be calculated using the mass of cement meeting ASTM C 150 or C 595 plus the weight of fly ash or pozzolan meeting ASTM C 618 and/or slag meeting ASTM C 989, if any.

7.2 Concrete for Wear Resistance

7.2.1 Aggregate of up to 4 mm particle size shall consist mainly of quartz or materials of at least equivalent hardness and coarser particles, of natural or artificial stone possessing high wear resistance. The aggregate grading should be such that it is as coarse as possible.

7.2.2 Concrete for exposure to service temperatures up to 250°C shall be made with aggregates which have proved suitable in accordance with relative Clause of ASTM for exposure to such temperatures. The concrete should be allowed to dry out before it is heated for the first time, the latter being performed as slowly as possible.

8. CONCRETE QUALITY, MIXING AND PLACING

8.1 General

8.1.1 Concrete shall be proportioned to provide an average compressive strength as prescribed in Section 5.3.2 of ACI 318M-89 as well as satisfy the durability criteria of Clause 7. Concrete shall be produced to minimize frequency of strengths below f_c' as prescribed in 9.2.3.

8.1.2 Requirements for f_c' shall be based on tests of cylinders made and tested as prescribed in 9.2 .

8.1.3 Unless otherwise specified. shall be based on 28-day tests. If other than 28 days, test age for f_c' shall be as indicated in design drawings or specifications.

8.1.4 Where design criteria in IPS-E-CE-200 provide for use of a splitting tensile strength value of concrete, laboratory tests shall be made in accordance with "Specification for Lightweight Aggregates for Structural Concrete" (ASTM C 330) to establish value of f_{ct} corresponding to specified value of f_c'.

8.1.5 Splitting tensile strength tests shall not be used as a basis for field acceptance of concrete.

8.2 Selection of Concrete Proportions

8.2.1 Proportions of materials for concrete shall be established to provide:

a) Workability and consistency to permit concrete to be worked readily into forms and around reinforcement under conditions of placement to be employed, without segregation or excessive bleeding.

b) Resistance to special exposures as required by Clause 7.

c) Conformance with strength test requirements of Clause 9.8.

8.2.2 Where different materials are to be used for different portions of proposed work, each combination shall be evaluated.

8.2.3 Concrete proportions, including water-cement ratio, shall be established on the basis of field experience and/or trial mixtures specified in Section 5.3 of ACI 318M-89, except as permitted in Section 5.4 of same Code or required by Clause 7 of this Standard.

8.2.4 Upon AR approval, for small concrete works, concrete proportions may be based on weight of cement as specified below:

Structural Concrete	(f_c' = 21 MPa, or 210 kg/cm^2)	300 kg
Non Structural Concrete	(f_c' = 18 MPa, or 180 kg/cm^2)	250 kg
Lean Concrete	(f_c' = 8 MPa, or 80 kg/cm^2)	150 kg

9. EVALUATION AND ACCEPTANCE OF CONCRETE

9.1 Frequency of Testing

9.1.1 Samples for strength tests of each class of concrete placed each day shall be taken not less than once a day, nor less than once for each 120 m^3 of concrete, nor less than once for each 500 m^2 of surface area for slabs or walls.

9.1.2 On a given project, if total volume of concrete is such that frequency of testing required by 9.1.1 would provide less than five strength tests for given class of concrete, tests shall be made from at least five randomly selected batches or from each batch if fewer than five batches are used.

9.1.3 A strength test shall be the average of the strength of two cylinders made from the same sample of concrete and tested at 28 days or at test age designated for determination of f_c'.

9.2 Laboratory-Cured Specimens

9.2.1 Samples for strength tests shall be taken in accordance with "Standard Method of Sampling Freshly Mixed Concrete" (ASTM C 172-82).

9.2.2 Cylinders for strength tests shall be molded and laboratory cured in accordance with "Standard Practice for Making and Curing Concrete Test Specimens in the Field" (ASTM C 31-87) and tested in accordance with "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens" (ASTM C 39-86).

9.2.3 Strength level of an individual class of concrete shall be considered satisfactory if both of the following requirements are met:

a) Average of all sets of three consecutive strength tests equal or exceed f_c'.
b) No individual strength test (average of two cylinders) falls below f_c' by more than 3.5 MPa.

9.2.4 If either of the requirements of 9.2.3 are not met, steps shall be taken to increase the average of subsequent strength test results. Requirements of 9.4. shall be observed if requirement of 9.2.3 (b) is not met.

9.3 Field-Cured Specimens

9.3.1 The AR may require strength tests of cylinders cured under field conditions to check adequacy of curing and protection of concrete in the structure.

9.3.2 Field-cured cylinders shall be cured under field conditions in accordance with "Standard Practice for Making and Curing Concrete Test Specimens in the Field" (ASTM C 31-87).

9.3.3 Field-cured test cylinders shall be molded at the same time and from the same samples as laboratory-cured test cylinders.

9.3.4 Procedures for protecting and curing concrete shall be improved when strength of field-cured cylinders at test age designated for determination of f_c’ is less than 85 percent of that of companion laboratory-cured cylinders. The 85 percent limitation shall not apply if field-cured strength exceeds f_c’ by more than 3.5 MPa.

9.4 Investigation of Low-Strength Test Results

9.4.1 If any strength test (Clause 9.1.3) of laboratory-cured cylinders falls below specified value of f_c’ by more than 3.5 MPa [Clause 9.2.3(b)] or if tests of field-cured cylinders indicate deficiencies in protection and curing (Clause 9.3.4), steps shall be taken to assure that load-carrying capacity of the structure is not jeopardized.

9.4.2 If the likelihood of low-strength concretes is confirmed and computations indicate that load-carrying capacity may have been significantly reduced, tests of cores drilled from the area in question may be required in accordance with "Standard Method of Obtaining and Testing Drilled Cores and Sawed Beams of Concrete" (ASTM C 42-84a). In such case, three cores shall be taken for each strength test more than 3.5 MPa below specified value of f_c’.

9.4.3 If concrete in the structure will be dry under service conditions, cores shall be air dried (temperature 15 to 30°C, relative humidity less than 60 percent) for 7 days before test and shall be tested dry. If concrete in the structure will be more than superficially wet under service conditions, cores shall be immersed in water for at least 40 hr. and be tested wet.

9.4.4 Concrete in an area represented by core tests shall be considered structurally adequate if the average of three cores is equal to at least 85 percent of f_c’ and if no single core is less than 75 percent of f_c’. Additional testing of cores extracted from locations represented by erratic core strength results shall be permitted.

9.4.5 If criteria of 9.4.4 are not met, and if structural adequacy remains in doubt, the AR may order load tests as outlined in section 20 of ACI 318 M-89 for the questionable portion of the structure, or take other appropriate action.

9.5 Preparation of Equipment and Place of Deposit

9.5.1 preparation before concrete placement shall include the following:

a) All equipment for mixing and transporting concrete shall be clean.

b) All debris and ice shall be removed from spaces to be occupied by concrete.

c) Forms shall be properly coated.

d) Masonry filler units that will be in contact with concrete shall be well drenched.

e) Reinforcement shall be thoroughly clean of ice or other deleterious coating.

f) Water shall be removed from place of deposit before concrete is placed unless a tremie is to be used, or unless otherwise permitted by the AR.

g) All laitance and other unsound material shall be removed before additional concrete is placed against hardened concrete.

9.6 Mixing

9.6.1 All concrete shall be mixed until there is a uniform distribution of materials and shall be discharged completely before mixer is recharged.

9.6.2 Ready-mixed concrete shall be mixed and delivered in accordance with requirements of "Standard Specification for Ready-Mixed Concrete" (ASTM C 94-86b) or "Standard Specification for Concrete Made by Volumetric Batching and Continuous Mixing" (ASTM C 685-86).

9.6.3 Job-mixed concrete shall be mixed in accordance with the following:

a) Mixing shall be done in a batch mixer of approved type.

b) Mixer shall be rotated at a speed recommended by the manufacturer.

c) Mixing shall be continued for at least 1-½ min after all materials are in the drum, unless a shorter time is shown to be satisfactory by the mixing uniformity tests of "Standard Specification for Ready-Mixed Concrete" (ASTM C 94-86b).

d) Materials handling, batching, and mixing shall also conform to applicable provisions of ASTM C 94-86b.

e) A detailed record shall be kept to identify:

1) number of batches produced;
2) proportions of materials used;
3) approximate location of final deposit in structure;
4) time and date of mixing and placing.

9.6.4 Normally, mechanical means shall be used for concrete mixing, and hand mixing shall only be allowed for small works, if approved by the AR.

9.6.5 Concrete mixing equipment shall be sufficient for size of the structures to be constructed and the concreting schedules, taking also into account the need to ensure continuous concreting for each structure.

9.6.6 Mechanical means shall be used for measuring concrete materials, and the concrete composition shall be constant and identical with those that proved to be optimum during the trial mixing for each class of concrete.

9.7 Testing of Concrete

9.7.1 Slump test

The slump test shall be performed in accordance with ASTM C 143-89a "Test Method for Slump of Portland Cement Concrete".

9.7.1.1 Different slumps are needed for various placements of concrete which is usually indicated in the concrete specifications.

9.7.1.2 Slumps given in Table 9 are for concrete consolidation by mechanical vibration.

TABLE 9 - RECOMMENDED SLUMPS FOR VARIOUS TYPES OF CONSTRUCTION

CONCRETE CONSTRUCTION	SLUMP, mm	
	MAXIMUM *	MINIMUM
Reinforced foundation walls and footings	75	25
Plain footings, caissons, and substructure walls	75	25
Beams and reinforced walls	100	25
Building columns	100	25
Pavements and slabs	75	25
Mass concrete	50	25

*** May be increased 25 mm for consolidation by hand methods such as rodding and spading.**

9.7.2 Sample test

Testing shall include compressive tests of molded concrete cylinders, or cube depending on what the design has been based on and slump tests for consistency.

9.7.2.1 Compressive test cylinders shall be prepared in sets of three cylinders for all tests. Specimens for each set shall be obtained at the same time and from the same batch of concrete. Tests shall be made for each 60 cubic meter pour or portion thereof. There shall be at least one test (3 specimens) for each day's concreting.

9.7.2.2 Samples from which compression test specimens are molded shall be secured in accordance with "Standard Method of Sampling Freshly Mixed Concrete" (ASTM C172-82).

Specimens made to check the adequacy of the proportions for strength of concrete or as a basis for acceptance of concrete shall be made and laboratory cured in accordance with "Standard Practice for Making and Curing Concrete Test Specimens in the Field "(ASTM C31-87a).

9.7.2.3 Each set of cylinders shall be tested as follows:

One cylinder at 7 days and,
Two cylinders at 28 days for acceptance.

9.7.2.4 The strength level of the concrete will be considered satisfactory so long as the averages of all sets of (3) three consecutive strength test results equal or exceed the specified 28 day crushing strength, and no individual strength test result falls below the specified strength by more than 2.5 MPa.

10. HANDLING, WORKING AND CURING OF CONCRETE

10.1 Handling of Concrete on Site

a) The method of concrete conveyance (e.g. by skip, conveyor belt, pumping, compressed air) and the composition of the concrete shall be coordinated so as to prevent segregation.

b) Conveying equipment shall be capable of providing a supply of concrete at site of placement without separation of ingredients and without interruptions sufficient to permit loss of plasticity between successive increments

c) Segregation shall also be prevented when concrete is poured into column or wall formwork, one way of achieving this being to pour the concrete through downpipes which terminate only a short distance above the point of deposit.

d) The use of pipes made of light metal is not permitted for pumping purposes.

e) The layout of pipes for conveying pumpable concrete shall be such as to ensure an uninterrupted flow of concrete through the pipes. Where concrete is conveyed by conveyor belt, scrapers and devices for holding the concrete together shall be provided at the throw-off point .

f) When placing concrete, care shall be taken that any reinforcement, fittings, or formwork surfaces, etc. in position for a later concreting phase do not become encrusted with concrete.

10.2 Depositing

10.2.1 Concrete shall be deposited as nearly as practical in its final position to avoid segregation due to rehandling or flowing.

10.2.2 Concerting shall be carried on at such a rate that concrete is at all times plastic and flows readily into spaces between reinforcement.

10.2.3 Concrete that has partially hardened or been contaminated by foreign materials shall not be deposited in the structure.

10.2.4 Retempered concrete or concrete that has been remixed after initial set shall not be used unless approved by the AR.

10.2.5 After concreting is started, it shall be carried on as a continuous operation until placing of a panel or section, as defined by its boundaries or predetermined joints, is completed except as permitted or prohibited by Clause 12.

10.2.6 Top surfaces of vertically formed lifts shall be generally level.

10.2.7 When construction joints are required, joints shall be made in accordance with Clause 12.

10.2.8 All concrete shall be thoroughly compacted by suitable means during placement and shall be thoroughly worked around reinforcement and embedded fixtures and into corners of forms.

10.3 Working of Concrete

10.3.1 Working time

Plain concrete shall be worked as soon as possible after mixing, and ready-mixed concrete as soon as possible after delivery. In any event, this shall be before it stiffens or changes in composition. The total time for mixing, transportation and puring of the concrete should generally not exceed 60 minutes under conditions that prevent segregation and maintain workability.

10.3.2 Compaction

1) Reinforcing bars shall be densely embedded in concrete, which shall be thoroughly compacted by means of vibration, punning, tamping, rapping of formwork, etc., particularly in corners and along the sides of the formwork.

2) While compacting by vibration methods, surface vibrators shall move slowly to enable the concrete below to soften while leaving behind them a solid mass. Where powerful surface vibrators are used, the layer of concrete after compaction should be not more than 200 mm deep. Where formwork vibrators are used, it shall be borne in mind that the depth to which they are able to compact the concrete is limited, this also depending on the design of the formwork.

3) Concrete with consistence range of soft to flowing properties may also be compacted by punning, taking care to work the concrete thoroughly to form a solid, void-free mass.

4) Tamping may be used for concrete of stiff consistence, the concrete after compaction being not more than 150 mm in depth. Tamping shall preferably be by mechanical means, although hand tamping is also permitted, and shall be carried out until the concrete softens whilst acquiring a closed surface structure. Individual layers should, where possible, be normal to the direction of compression, and tamping shall be in the direction of compression. Where this is not possible, the concrete shall be at least of plastic consistence in order to ensure that there are no tamping joints parallel to the direction of compression.

5) If no provision is made for construction joints, the time intervals between placing individual layers shall be kept as short as possible since, to achieve an effective bond between layers, no new layer shall be placed on one which has already set. Where immersion vibrators are used, the head shall penetrate into the lower layer, in which compaction has already taken place.

10.4 Curing

10.4.1 Concrete (other than high-early-strength) shall be maintained above 10°C and in a moist condition for at least the first 7 days after placement, except when cured in accordance with 10.4.7.

10.4.2 High-early-strength concrete shall be maintained above 10°C and in a moist condition for at least the first 3 days, except when cured in accordance with 10.4.7.

10.4.3 Until it has sufficiently hardened, concrete shall be protected from harmful effects such as severe cooling or heating, premature drying out (including by wind), leaching out by rain or flowing water, chemical attack, or vibration and impact which may disrupt the concrete and interfere with its bond to the reinforcement. This shall also apply to sealing mortar and to the concrete used as a filler for joints between precast members.

10.4.4 On flat surfaces such as pavements, sidewalks and floors, curing can be accomplished by immersion of the finished concrete, called ponding, which will prevent loss of moisture and is effective for maintaining a uniform temperature in the concrete. The curing water temperature should not be more than 11°C cooler than the concrete to prevent thermal stresses that could result in cracking.

10.4.5 Plastic sheet materials such as polyethylene film used for curing concrete should conform to ASTM C 171.

10.4.6 Curing compound should conform to ASTM C 309.

10.4.7 Accelerated curing

10.4.7.1 Curing by high pressure steam, steam at atmospheric pressure, heat and moisture, or other accepted processes, shall be permitted to accelerate strength gain and reduce time of curing.

10.4.7.2 Accelerated curing shall provide a compressive strength of the concrete at the load stage considered at least equal to required design strength at that load stage.

10.4.7.3 Members subjected to heat treatment shall be kept moist since hardening is not generally completed by the end of the treatment and the concrete dries out considerably during cooling.

10.4.7.4 Curing process shall be such as to produce concrete with a durability at least equivalent to the curing method of 10.4.1 or 10.4.2.

10.4.7.5 When required by the AR, supplementary strength tests in accordance with 9.3 shall be performed to assure that curing is satisfactory.

10.4.8 Cold weather concreting

10.4.8.1 Adequate equipment shall be provided for heating concrete materials and protecting concrete during freezing or near-freezing weather.

10.4.8.2 All concrete materials and reinforcement, forms, fillers, and ground with which concrete is to come in contact shall be free from frost.

10.4.8.3 Frozen materials or materials containing ice shall not be used.

10.4.8.4 Concrete that has been frozen just once at an early age may be restored to early normal strength by providing favorable curing conditions. Such concrete, however, is not as resistant to weathering nor is it as water tight as concrete that has not been frozen. Air-Entrained concrete is less susceptible to damage by early freezing than concrete without entrained air.

10.4.8.5 Concrete should not be cast on frozen concrete or on frozen ground. Aggregate shall be free from snow, ice and frost. If required, the water and, where necessary, the aggregate shall be preheated. Water at a temperature of above +70°C shall first be mixed with the aggregate before cement is added. Particularly for slender members it is advisable to increase the cement content or to use cement of a higher strength class, or both.

10.4.8.6 Accelerators shall not be used as a substitute for proper curing and frost protection. Also, the use of antifreeze compounds or other materials to lower the freezing point of concrete shall not be permitted.

10.4.8.7 Accelerators containing chlorides should not be used where there is an inservice potential for corrosion.

10.4.8.8 The temperature of fresh concrete as mixed should not be less than shown in lines 1, 2, or 3 of Table 10. Note that lower concrete temperature are recommended for heavy mass concrete sections and as at lower air temperature more heat is lost from concrete during transporting and placing; hence, the recommended temperatures shown in lines 1, 2 and 3 are higher for cold weather.

TABLE 10 - RECOMMENDED CONCRETE TEMPERATURE FOR COLD-WEATHER CONSTRUCTION; AIR-ENTRAINED CONCRETE

LINE	CONDITION		SECTIONS LESS THAN 300 mm THICK	SECTIONS 300 mm TO 0.9 m THICK	SECTIONS 0.9 TO 1.8 m THICK	SECTIONS OVER 1.8 m THICK
			°C	°C	°C	°C
1	Minimum temperature	Above -1°C	16	13	10	7
2	Fresh concrete as mixed in	-18 to -1°C	18	16	13	10
3	weather indicated °C	Below -18°C	21	18	16	13
4	Minimum temperature fresh concrete as placed and maintained		113	10	7	5
5	Maximum allowable gradual drop in temperature in first 24 hours after end protection		28	22	17	11

*** Placement temperatures listed are for normal-weight concrete. Lower temperatures can be used for lightweight concrete if justified by tests. For recommended duration of these temperatures, see Table 11.**

10.4.8.9 Table 11 has been adapted from "Cold Weather Concreting", (ACI 306-78). Cold weather is defined as that in which average daily temperature is less than 5°C, except that if temperatures above 10°C occur during at least 12 hours in any day, the concrete should no longer be regarded as winter concrete and normal curing practice should apply. For recommended concrete temperatures see Table 10.

Part B of Table 11 has been adapted from Table 7.7 of ACI 306-78. The values shown are approximations and will vary according to the thickness of concrete, mix proportions, etc. They are intended to represent the ages at which supporting forms can be removed. For recommended concrete temperatures, see Table 10.

10.4.8.10 The concrete carried by the ready mix truck to the site should be placed in the forms before its temperature drops below that given on line 4 of Table 10, and that temperature should be maintained for the duration of the protection period.

10.4.8.11 Columns and walls should not be cast on frozen foundations, because chilling the bottom of the column or wall will cause weak concrete.

10.4.8.12 Heat can be retained in the concrete by covering it with commercial insulating blanket or other insulating materials, which should be kept dry and in close contact with concrete or formwork for maximum efficiency.

The resistance to heat transfer (R) values for common insulation materials are given in Table 12.

10.4.8.13 Insulating blankets for construction are made of fiberglass, sponge rubber, open-cell polyurethane foam, venyl foam, mineral wool, or cellulose fibers. The outer covers are made of canvas, woven polyethylene, or other tough fabrics that will take rough handling.

10.4.8.14 No concrete shall be placed during heavy rain, snow or when ambient temperature falls below -18°C, unless proper sheltering or heated enclosure are provided and written approval of AR is obtained.

TABLE 11 - A) RECOMMENDED DURATION OF RECOMMENDED CONCRETE TEMPERATURE IN COLD WEATHER, - AIR-ENTRAINED CONCRETE

PERMANENT SERVICE CATEGORY	FOR DURABILITY		FOR SAFE STRIPPING STRENGTH	
	CONVENTIONAL CONCRETE* DAYS	HIGH-EARLY-STRENGTH CONCRETE** DAYS	CONVENTIONAL CONCRETE* DAYS	HIGH-EARLY-STRENGTH CONCRETE** DAYS
Lightly stressed, no exposure, ♣ favorable moist-curing	2	1	2	1
Lightly stressed, exposed, but later has favorable moist-curing	3	2	3	2
Moderately stressed exposed ♣	3	2	6	4
Fully stressed exposed ♣	3	2	See B below	

B) RECOMMENDED DURATION OF RECOMMENDED CONCRETE TEMPERATURE FOR FULLY STRESSED, EXPOSED, AIR-ENTRAINED CONCRETE

REQUIRED PERCENTAGE OF DESIGN STRENGTH f_c'	DAYS AT 10°C			DAYS AT 21°C		
	TYPE OF PORTLAND CEMENT			TYPE OF PORTLAND CEMENT		
	ASTM I	II	III	ASTM I	II	III
50	6	9	3	4	6	3
65	11	14	5	8	10	4
85	21	28	16	16	18	12
95	29	35	26	23	24	20

*** Made with ASTM type 1 or 11 Portland cement.**

**** Made with ASTM type 111 Portland cement, or an accelerator, or an extra 20% of cement.**

♣ "Exposure" means subject to freezing and thawing.

Note:

For concrete that is not air-entrained, ACI 306-78 states that protection for durability should be at least twice the number of days listed.

TABLE 12 - INSULATION VALUES OF VARIOUS MATERIALS

A		
INSULATING MATERIAL	**DENSITY**	**THERMAL RESISTANCE, R FOR THICKNESS OF MATERIAL ***
	kg/m^3	**10 mm, (°Cm^2)/W**
Board and Slabs		
Expanded polyurethane (R-11 exp.)	24	0.433
Expanded polystyrene extruded	35	0.347
Expanded polystyrene extruded	29	0.277
Glass fiber, organic bonded	64 to 144	0.277
Expanded polystyrene molded beads	16	0.248
Mineral fiber with resin binder	240	0.239
Mineral fiberboard, wet felted	256 to 272	0.204
Vegetable fiberboard sheathing	288	0.182
Cellular glass	136	0.182
Laminated paperboard	480	0.139
Particle board (low density)	592	0.128
Plywood	545	0.087
Loose Fill		
Wood fiber, soft woods	32 to 56	0.231
Perlite (expanded)	80 to 128	0.187
Vermiculite (exfoliated)	64 to 96	0.157
Vermiculite (exfoliated)	112 to 132	0.148
Sawdust or shaving	128 to 240	0.154

B		
INSULATING MATERIAL	**APPROXIMATE THICKNESS OF MATERIAL**	**THERMAL RESISTANCE, R**
	mm	**(°Cm^2)/W**
Mineral fiber blanket fibrous form (rock, slag or glass) 5 to 32 kg/m^3	50 to 70	1.23
	75 to 88	1.94
	88 to 165	3.34
	150 to 175	3.87
	215	5.28
Mineral fiber loose fill (rock, slag or glass) 10 to 32 kg/m^3	95 to 125	1.94
	165 to 220	3.34
	190 to 250	3.87
	260 to 350	5.28

*** Values are from ASHRAE Handbook of Fundamentals, 1977, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., New York .**

10.4.9 Hot weather concreting

10.4.9.1 During hot weather, proper attention shall be given to ingredients, production methods, handling, placing, protection, etc. For details refer to "Hot Weather Concreting" recommended by ACI committee 305.

10.4.9.2 At higher temperatures greater amount of water is required to hold slump constant than is needed at lower temperatures. Adding water without adding cement results in a higher water-cement ratio,thereby lowering the late-age strength and adversely affecting other desirable properties of the hardened concrete.

10.4.9.3 Besides reducing the strength and increasing the mixing water requirement, high temperatures of fresh concrete have other harmful effects. Setting time is reduced; high temperatures increase the rate of concrete hardening and thereby shorten the length of time within which the concrete can be transported, placed, and finished.

10.4.9.4 In hot weather the tendency to crack is increased both before and after hardening. Excessively rapid evaporation of water from plastic concrete can cause plastic-shrinkage cracks before the surface has hardened.

10.4.9.5 Air entrainment is also affected in hot weather. At elevated temperatures, concrete requires an increase in the amount of air-entraining admixture to obtain a given total air content.

10.4.9.6 The usual method of maintaining low concrete temperatures is to control the temperature of the concrete materials. One or more of the ingredients should be cooled before mixing. In hot weather the aggregates and water should be kept as cool as practicable.

10.4.9.7 Cold water will effect a moderate reduction in the concrete temperature. It should be stored in tanks that are not exposed to the direct rays of the sun. Tanks and pipelines carrying the mixing water should be buried, insulated, shaded or painted white to keep water at the lowest practical temperature.

10.4.9.8 Water can be cooled by refrigeration, liquid nitrogen, or crushed ice.

10.4.9.9 Aggregates have a pronounced effect on the fresh concrete temperature because they present 60% to 80% of the total weight of concrete.

10.4.9.10 "Specification for Ready Mixed Concrete" (ASTM C 94) shall be followed which states that during hot weather the time limit required for discharge of concrete shall be completed within one hour or even 45 minutes.

10.4.9.11 Plastic cracking is usually associated with hot-weather concreting; however it can occur at any time when atmospheric conditions produce rapid evaporation of moisture from the concrete surface.

10.4.9.12 In hot weather and where careful inspection is maintained, a retarding admixture is beneficial in delaying the setting time while increasing the rate of slump loss. Retarding admixtures should conform to the requirements of ASTM C 494, Type B.

10.5 Concreting Under Water

10.5.1 As a rule, only plain concrete placed by means of stationary tremies is suitable as underwater concrete.

10.5.2 Underwater concrete shall be placed rapidly and steadily. The water in the enclosure shall be still, i.e. there shall be no flow of current. It shall be possible for the levels of water inside and outside the enclosure to reach equilibrium.

10.5.3 For water depths up to 1 m, the concrete may be placed by carefully causing it to advance at its natural angle of flow without segregating. Prior to this, it shall be deposited above water level.

10.5.4 For water depths exceeding 1 m, the concrete shall be placed so that it does not fall freely through the water, avoiding the washing out of cement and, where possible, the formation of interlayers of cement slurry.

10.5.5 For secondary structural members, the concrete may be deposited in successive layers using hops or traveling tremies standing on the foundation base or on the surface of the individual layers of concrete.

10.5.6 Stationary tremies or closed containers which project sufficiently far into concrete which has not yet set may be used for making all types of member provided that the formwork is adequately watertight.

10.5.7 Tremies shall be kept sufficiently immersed in concrete which has already been placed for this to be displaced sidewards and upwards by the fresh quantity of concrete discharged by the tremies. At no point shall the displaced concrete come into contact with water. Stationary tremies shall be spaced so that the lateral flow distances of the concrete are as short as possible.

10.5.8 During concreting, the tremie shall be carefully raised, its discharge pipe remaining in the concrete. Where several tremies are used, they shall be simultaneously and uniformly fed with concrete.

10.5.9 When placing the concrete into tremies or other containers, it shall be compacted using immersion vibrators for air expulsion.

10.5.10 Alternatively, underwater concrete may be made by injecting low-segregation grout from below into a mass of suitably graded aggregate (i.e., not containing fines or medium sized particles), the grout rising at an even rate.

10.5.11 The slump of the concrete should be not less than 125 mm and the cement content not less than 350 kg/m^3.

10.5.12 Concrete should flow without segregation, therefore the aim in proportioning the mixture should be to obtain a good plastic mix with high workability.

10.5.13 Rounded aggregates with higher percentage of fines and entrained air will provide the desired consistency.

10.5.14 About 10% to 15% more cement should be used than for a similar mixture placed in dry air.

10.6 Mortars and Grouts

For general information reference is made to IPS-M-CE-165 and for grout for bonded prestresting tendons refer to Section 18.16 of ACI 318M-89.

11. FORMWORK

11.1 General Considerations

The design, engineering and construction of the formwork shall be the responsibility of the contractor but will be subject to the approval by the AR*. Typical drawings showing the proposed formwork shall be submitted by the contractor for approval by the AR before starting the construction.

Formwork should be designed so that concrete slabs, walls and other members will be of correct dimensions, shape, alignment, elevation and position within established tolerances. Vertical and lateral loads must be carried to the ground by the formwork system or by the in-place construction that has adequate strength for that purpose.

A design analysis should be made for all formwork, stability and buckling should be investigated in all cases.

11.2 Design Considerations

11.2.1 Loads and unit stresses

Formwork and its supporting structure, shall be designed to resist all vertical and horizontal forces. The design also should consider the effect of rate-of-discharge and the method of compaction. For supports and walls higher than 3 m, the rate at which the concrete is discharged shall be adjusted to the load bearing capacity of the formwork. Unit stresses for use in the design of formwork shall be in accordance with Section 2.3 of ACI 347-78.

When fabricated formwork, shoring, or scaffolding units are used, manufacturer's recommendations for allowable loads may be followed.

*** AR Authorized Representative of the Owner**

11.2.2 Shores and bracing

Shores are vertical or inclined support members which should be designed in such a manner to carry the weight of formwork, concrete and construction loads. Bracing should be provided in vertical and horizontal planes where required to provide stiffness and to prevent buckling of individual members. A rational analysis should be used to determine the number of floors to be shored, reshored and backshored and to determine the loads transmitted to the floors, shores and reshores or backshores as a result of the construction sequence. For detailed information refer to Chapter 2 of ACI 347R.

11.2.3 Foundations for formwork

Proper foundations on ground such as mudsills, spread footing, or pile footings should be provided. If soil under mudsills is or may become incapable of supporting superimposed loads without appreciable settlement, it should be stabilized or other means of support should be provided. No concrete should be placed on formwork supported on frozen ground.

11.2.4 Settlement

Formwork should be so designed and constructed that vertical adjustments can be made to compensate for take-up and settlements. In addition to the Design Considerations specified above, requirements of Section 6.1 of ACI 318M-89 shall be satisfied .

11.3 Materials for Formwork

11.3.1 General

The selection of materials suitable for formwork should be based on maximum economy to the project, consistent with safety and the quality required in the finished work, subject to approval by the AR.

11.3.2 Properties

The formwork materials commonly used consists of timber, plywood, steel, concrete, brick, plastics, fiberglass, etc. For more details refer to Chapter 4 of ACI 347-78.

11.3.2.1 Form sheathing

Sheathing is the supporting layer of formwork closest to the concrete. It may be in direct contact with the concrete or be separated from it by a form liner.

In selection and use of materials important considerations are: strength, stiffness, release, reuse and cost per use, surface characteristics, resistance to mechanical damage, workability for cutting, drilling and attaching fasteners, adaptability to weather and extreme field conditions, temperature and moisture, weight and ease of handling.

11.3.2.2 Structural supports

Structural support systems carry the sheathing for which important considerations are: strength, stiffness, dimensional accuracy and stability, workability for cutting, drilling and attaching fasteners, weight, cost and durability.

11.3.2.3 Accessories

Accessories consists of: form ties, form anchors, form hangers and side form spacers. For more details of accessories refer to Section 4.3 of ACI 347-78.

11.3.3 Form coatings or release agents

11.3.3.1 Form coatings or sealers are usually applied in liquid form to contact surface either during manufacturer or in the field to serve one or more of the following purposes:

a) Alter the texture of the contact surface.
b) Improve the durability of the contact surface.
c) Facilitate release from concrete during stripping.
d) Seal the contact surface from intrusion of moisture.

11.3.3.2 Form release agents are applied to the form contact surfaces to prevent bond and thus facilitate stripping. Generally manufacturer's recommendations should be followed in the use of coatings, sealers, and release agents, but independent investigation of the performance by specialized organizations is recommended before use.

11.4 Constructional Aspect

11.4.1 Safety precautions

Construction procedures must be planned in advance to insure the safety of personnel and the integrity of the finished structure. Some of the safety provisions which should be considered are:

- Erection of safety signs and barricades to keep unauthorized personnel clear of areas in which erection, concrete placing, or stripping is underway.
- Providing experienced foremen during concrete placement to assure early recognition of possible form displacement or failure.
- A supply of extra shores or other material and equipment that might be needed in an emergency case.
- Provision for adequate illumination of the formwork;
- Provision of a program of field safety inspections of formwork, etc.

11.4.2 Construction practices and workmanship

Generally the following should be considered:

- Joints or splices in sheathing, plywood panels and bracing should be staggered.
- Forms should be sufficiently tight to prevent loss of mortar from the concrete.
- Forms should be inspected and checked before the reinforcing steel is placed to insure that the dimensions and location of the concrete members conform to the working drawings.
- Forms should be checked for camber when specified.
- Control joints, construction joints, and expansion joints should be installed as specified.
- Forms should be thoroughly cleaned of all dirt, mortar, and foreign matter and coated with a release agent before each use.
- Building materials, including concrete, must not be dropped or piled on the formwork in such manner as to damage or overload it.

11.4.3 Tolerances

Tolerance is a specified permissible variation from lines, grades, or dimensions given in contract documents. Tolerances for concrete structures should comply with the requirements of ACI 117-81 and Section 3.3 of ACI 347-78. Where tolerances are not stated in the specifications or drawings for any individual structure permissible deviations from established lines, grades, and dimensions shall follow the recommendations stated under Section 3.3 of ACI 347-78. The contractor is expected to set and maintain concrete forms so as to insure execution of works within the tolerance limits.

11.4.4 Shoring and centering

Shoring must be supported on satisfactory foundations such as spread footing, mudsills or piling. All members must be straight and true without twists or bends.

Vertical shores must be erected so that they cannot tilt and must have firm bearing. Inclined shores must be braced securely against slipping or sliding. Centering is the highly specialized temporary support system used in the construction of any continuous structure, where the entire temporary support is lowered as a unit. The lowering of the centering is generally accomplished by the use of sand boxes, jacks or wedges beneath the supporting members.

11.4.5 Removal of forms and supports

In the absence of other information the recommended periods before removal of formwork given in Table 13 should be used for concrete made with ordinary or sulfate-resisting Portland cement. Table 13 relates to the surface temperature of the concrete but, when this can not be obtained, air temperature may be used.

Table 13 should not be used if accelerated curing method or sliding forms are used. In addition to above statements, requirements of Section 6.2 "Remove of Forms and Shores" of ACI 318M-89 should be observed.

The formwork should be removed without shock, as the sudden removal of wedges is equivalent to an impact load on the partially hardened concrete. Materials and plant should not be placed on any new construction in such a manner as to cause damage.

It may be possible to remove the formwork sooner than specified in Table 13, provided that the results of strength tests or concrete specimens are satisfactory as approved by AR.

TABLE 13 - MINIMUM PERIOD BEFORE REMOVAL OF FORMWORK (CONCRETE MADE WITH ORDINARY OR SULFATE - RESISTING PORTLAND CEMENT)

TYPE OF FORMWORK	MINIMUM PERIOD BEFORE REMOVAL		
	SURFACE TEMPERATURE OF CONCRETE		
	16°C and above	7°C	t (any temperature between 0°C and 25°C)
Vertical formwork to columns, walls and large beams	12h	18h	$\frac{300}{t+10}$ h
Soffit formwork to slabs	4 days	6 days	$\frac{100}{t+10}$ days
Soffit formwork to beams and props to slabs	10 days	15 days	$\frac{250}{t+10}$ days
Props to beam	14 days	21 days	$\frac{360}{t+10}$ days

11.5 Formwork for Special Methods of Construction

11.5.1 General

Special formworks like slipforms, permanent forms, etc. are often encountered in the construction of Petroleum Industry’s different projects. In the following clauses short description is presented for such instances. For more detailed information refer to Chapter 6 of ACI 347-78.

11.5.2 Slipforms

Horizontal and vertical slipforms should be designed and constructed and the sliding operation should be carried out under the supervision of a person or persons experienced in slipform work.

Maximum rate of slide should be limited by the rate for which the forms are designed. The level of the hardened concrete in the form must be checked frequently by the use of a probe to establish safe lifting rates.

Care must be taken to prevent drifting of the forms from alignment or designed dimensions, and to prevent torsional movement.

Detailed records of both vertical and lateral form movements should be maintained throughout the slipform operation. For more detailed information refer to Section 6.3 of ACI 347-78.

11.5.3 Permanent forms

Permanent forms are forms left in place that may or may not become and integral part of the structural frame. Particular care should be taken in the design of such forms to minimize distortion or deformation of the form or supporting members under the construction loads.

The contractors should submit fully detailed shop drawings for all permanent forms to AR for review and approval. For more detailed information refer to Section 6.4 of ACI 347-78.

11.5.4 Forms for precast concrete

This type of forms are used for precast concrete items that may be either load bearing or non load-bearing members for structural or architectural use.

To assure uniformity of appearance in the cast members, care should be taken that the contact surfaces are of uniform quality and texture. Where required to allow early reuse of forms, provisions should be made to use accelerated curing processes, such as steam curing, or other approved methods. Methods of lifting precast units from forms should be approved by the AR.

11.5.5 Other types of special methods

For detailed information on forms for prestressed and precast concrete and concrete placed underwater refer to Sections 6.5, 6.6 and 6.8 of ACI 347-78.

11.6 Shrinkage and Temperature Reinforcement

11.6.1 Reinforcement for shrinkage and temperature stresses normal to flexural reinforcement shall be provided in structural slabs where the flexural reinforcement extends in one direction only.

11.6.2 Shrinkage and temperature reinforcement shall be in accordance with Chapter 11 of ACI 318.

11.7 Crack Control

11.7.1 The crack width for interior members and exterior members shall not be more than 0.4 mm and 0.32 mm respectively. (In corrosive environments the crack width shall not be more than 0.05 mm.)

11.7.2 The crack width for slabs acting as interior members and exterior members shall not be more than 0.35 mm and 0.29 mm respectively.

11.7.3 Members in which it is likely that cracks will extend over their gross cross section shall be given special protection, if they are subject to attack by water with a high chloride content.

11.7.4 The check for crack control in bundles of bars shall be carried out on the basis of the reference diameter.

11.7.5 When there are bundles of bars with a diameter greater than 36 mm in members predominantly subjected to flexure, there shall be provision of skin reinforcement in the tension zone of the member in order to ensure adequate crack behavior.

11.7.6 Only reinforcing fabric with horizontal and vertical bars spaced not more than 100 mm apart shall be used as skin reinforcement. The cross section of the skin reinforcement across the bundle of bars, α_{sh}, shall be obtained from following equation and shall be at least 200 mm^2/m in the longitudinal direction:

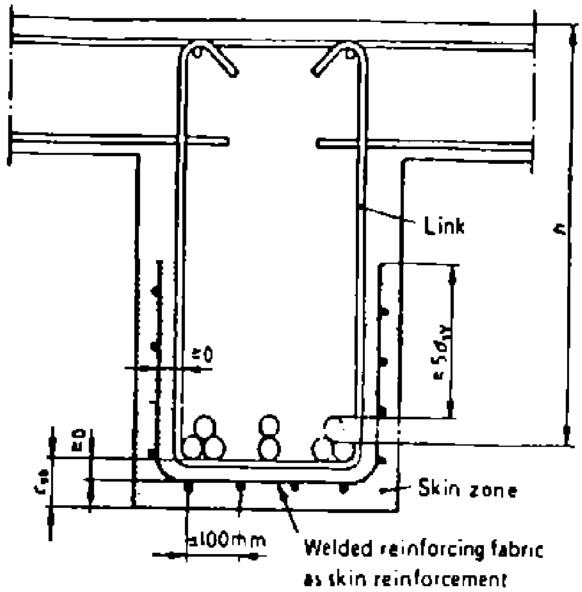
$$\alpha_{sh} \geq 2\, C_{sb}$$

Where:

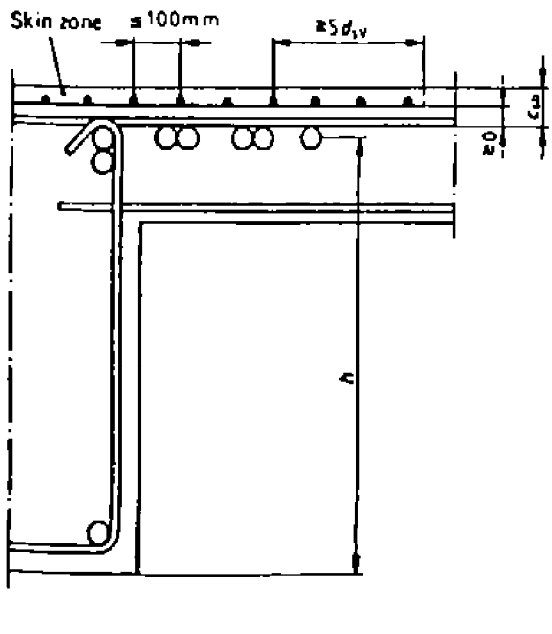
C_{sb} is the minimum concrete cover of the bundles.

11.7.7 The skin reinforcement shall extend beyond the innermost layer of bundles of the bottom reinforcement at the sides of the member by an amount equal to at least 5 d_{sv}[1)] (see Fig. 1a), whilst it shall extend beyond the outermost layer of bundles of the top reinforcement of T-beams by the same amount (see Fig. 1b). The skin reinforcement may be included in the flexural tensile, transverse or shear reinforcement providing that all requirements relating to these types of reinforcement are satisfied.

1) Diameter of a single bar of area equivalent to that of bundle of bars.



a) Bottom reinforcement



b) Top reinforcement

EXAMPLES OF ARRANGEMENT OF SKIN REINFORCEMENT
IN CROSS SECTION OF A T-BEAM

Fig. 1

12. CONSTRUCTION AND CONTROL JOINTS

12.1 Construction Joints

12.1.1 Surface of concrete construction joints shall be cleaned and laitance removed.

12.1.2 Immediately before new concrete is placed, all construction joints shall be wetted and standing water removed.

12.1.3 Construction joints shall be so made and located as not to impair the strength of the structure. Provision shall be made for transfer of shear and other forces through construction joints.

12.1.4 Construction joints in floors shall be located within the middle third of spans of slabs, beams, and girders. Joints in girders shall be offset a minimum distance of two times the width of intersecting beams.

12.1.5 Beams, girders, or slabs supported by columns or walls shall not be cast or erected until concrete in the vertical support members is no longer plastic.

12.1.6 Beams, girders, haunches, drop panels and capitals shall be placed monolithically as part of a slab system, unless otherwise shown in design drawings or specifications.

12.2 Control Joints

12.2.1 Control joints should be constructed to permit transfer of loads perpendicular to the plane of the slab or wall.

12.2.2 The spacing of control joints in floors on ground depend on (1) slab thickness, (2) shrinkage potential of the concrete and (3) curing environment.

12.2.3 Control joints in walls should be spaced not more than about 6 m apart. In addition control joints should be placed where abrupt changes in thickness or height occurs, and near corners-if possible as close as 1500 mm.

12.2.4 Construction joints are merely stopping places in the process of construction. A true construction joint should bond new concrete to existing concrete and permit neither horizontal nor vertical movement.

13. DETAILS OF REINFORCEMENT

13.1 Standard Hooks

The term "standard hook" as used in this Standard shall mean one of the following:

13.1.1 180-deg bend plus $4d_b$ extension, but not less than 60 mm at free end of bar.

13.1.2 90-deg bend plus $12d_b$ extension at free end of bar.

13.1.3 For strirrup and tie hooks:

a) ϕ15 bar and smaller, 90-deg bend plus 6 d_b extension at free end of bar, or
b) ϕ20 and ϕ25 bar, 90-deg bend plus 12 d_b extension at free end of bar, or
c) ϕ25 bar and smaller, 135-deg bend plus 6 d_b extension at free end of bar.

13.2 Minimum Bend Diameters

13.2.1 Diameter of bend measured on the inside of the bar, other than for stirrups and ties in sizes ϕ10 through ϕ15 shall not be less than the values in Table 14.

13.2.2 Inside diameter of bend for stirrups and ties shall not be less than 4 d_b for ϕ15 bar and smaller. For bars larger than ϕ15, diameter of bend shall be in accordance with Table 14.

13.2.3 Inside diameter of bend in welded wire fabric (plain or deformed) for stirrups and ties shall not be less than 4 d_b for deformed wire larger than D6 and 2 d_b for all other wires. Bends with inside diameter of less than 8 d_b shall not be less than 4 d_b from nearest welded intersection.

TABLE 14 - MINIMUM DIAMETERS OF BEND

BAR SIZE	MINIMUM DIAMETER
ϕ10 ϕ25	6 d_b
ϕ20 and ϕ35	8 d_b
ϕ45 and ϕ55	10 d_b

13.3 Bending

13.3.1 All reinforcement shall be bent cold, unless otherwise permitted by the AR.

13.3.2 Reinforcement partially embedded in concrete shall not be field bent, except as shown on the design drawings or permitted by the AR.

13.4 Surface Conditions of Reinforcement

13.4.1 At time concrete is placed, metal reinforcement shall be free from mud, oil, or other nonmetallic coatings that adversely affect bonding capacity.

13.4.2 Metal reinforcement, except prestressing tendons, with rust, mill scale, or a combination of both shall be considered satisfactory, provided the minimum dimensions (including height of deformations) and weight of a hand-wire-brushed test specimen are not less than applicable ASTM specification requirements.

13.4.3 Prestressing tendons shall be clean and free of oil, dirt, scale, pitting and excessive rust. A light oxide is permissible.

13.5 Placing Reinforcement

13.5.1 Reinforcement, prestressing tendons, and ducts shall be accurately placed and adequately supported before concrete is placed, and shall be secured against displacement within tolerances permitted in subclause 13.5.2.

13.5.2 Unless otherwise specified by the AR, reinforcement, prestressing tendons, and prestressing ducts shall be placed within the following tolerances:

13.5.2.1 Tolerance for depth d, and minimum concrete cover in flexural members, walls and compression members shall be as follows:

	TOLERANCE ON d	TOLERANCE ON MINIMUM CONCRETE COVER
d ≤200 mm	±10 mm	-10 mm
d >200 mm	±12 mm	-12 mm

Except that tolerance for the clear distance to formed soffits shall be minus 6 mm, and tolerance for cover shall not exceed minus 1/3 the minimum concrete cover required in the design drawings or specifications.

13.5.2.2 Tolerance for longitudinal location of bends and ends of reinforcement shall be ±50 mm except at discontinuous ends of members where tolerance shall be ±12 mm.

13.5.3 Welded wire fabric (with wire size not greater than W5 or D5) used in slabs not exceeding 3 m in span may be curved from a point near the top of slab over the support to a point near the bottom of slab at midspan, provided such reinforcement is either continuous over, or securely anchored at support.

13.5.4 Welding of crossing bars shall not be permitted for assembly of reinforcement unless authorized by the AR.

13.6 Spacing Limits for Reinforcement

13.6.1 Clear distance between parallel bars in a layer shall be not less than d_b but not less than 25 mm.

13.6.2 Where parallel reinforcement is placed in two or more layers, bars in the upper layers shall be placed directly above bars in the bottom layer with clear distance between layers not less than 25 mm.

13.6.3 In spirally reinforced or tied reinforced compression members, clear distance between longitudinal bars shall be not less than 1.5 d_b nor 40 mm .

13.6.4 Clear distance limitation between bars shall apply also to the clear distance between a contact lap splice and adjacent splices or bars.

13.6.5 In walls and slabs other than concrete joist construction, primary flexural reinforcement shall be spaced not farther apart than three times the wall or slab thickness, nor 500 mm.

13.6.6 Bundled bars

13.6.6.1 Groups of parallel reinforcing bars bundled in contact to act as a unit shall be limited to four in any one bundle.

13.6.6.2 Bundled bars shall be enclosed within stirrups or ties.

13.6.6.3 Bars larger than ϕ35 shall not be bundled in beams.

13.6.6.4 Individual bars within a bundle terminated within the span of flexural members shall terminate at different points with at least 40 d_b stagger.

13.6.6.5 Where spacing limitations and minimum concrete cover are based on bar diameter d_b, a unit of bundled bars shall be treated as a single bar of a diameter derived from the equivalent total area.

13.6.7 Prestressing tendons and ducts

13.6.7.1 Clear distance between pretensioning tendons at each end of a member shall be not less than 4 d_b for wire, nor 3 d_b for strands. Closer vertical spacing and bundling of tendons may be permitted in the middle portion of a span.

13.6.7.2 Post-tensioning ducts may be bundled if shown that concrete can be satisfactorily placed and if provision is made to prevent the tendons, when tensioned, from breaking through the duct.

13.7 Concrete Protection for Reinforcement

13.7.1 Cast-In-Place concrete (nonprestressed)

The following minimum concrete cover shall be provided for reinforcement:

	Minimum Cover, mm
a) Concrete cast against and permanently exposed to earth	75
b) Concrete exposed to earth or weather:	
ϕ20 through ϕ55 bars	50
ϕ15 bar, W31 or D31 wire, and smaller	40
c) Concrete not exposed to weather or in contact with ground:	
Slabs, walls, joists:	
ϕ45 and ϕ55 bars	40
ϕ35 bar and smaller	20
Beams, columns:	
Primary reinforcement, ties, stirrups, spirals	40
Shells, folded plate members:	
ϕ20 bar and larger	20
ϕ15 bar, W31 or D31 wire, and smaller	15
In contact with or above sea water	
underside and sides of slabs	75
top side of slab	50
beams	75

13.7.2 Precast concrete (manufactured under plant control conditions)

The following minimum concrete cover shall be provided for reinforcement:

	Minimum Cover, mm
a) Concrete exposed to earth or weather:	
Wall Panels	
ϕ45 and ϕ55 bars	40
ϕ35 bar and smaller	20
Other members:	
ϕ45 and ϕ55 bars	50
ϕ20 through ϕ35 bars	40
ϕ15 bar, W31 or D31 wire, and smaller	30
b) Concrete not exposed to weather or in contact with ground:	
Slabs, walls, joists:	
ϕ45 and ϕ55 bars	30
ϕ35 bar and smaller	15

Beams, columns:	
Primary reinforcement	d_b but not less than 15 and need not exceed 40
Ties, stirrups, spirals	10
Shells, folded plate members:	
ϕ20 bar and larger	15
ϕ15 Bar, W31 or D31 wire, and smaller	10
In contact with or above sea water	
underside and sides of slab	75
top side of slab	50
beams	75

13.7.3 Prestressed concrete

13.7.3.1 The following minimum concrete cover shall be provided for prestressed and nonprestressed reinforcement, ducts, and end fittings, except as provided in Sections 13.7.3.2 and 13.7.3.3:

	Minimum Cover, mm
a) Concrete cast against and permanently exposed to earth	75
b) Concrete exposed to earth or weather:	
Wall panels, slabs, joists	30
Other members	40
c) Concrete not exposed to weather or in contact with ground:	
Slabs, walls, joists	20
Beams, columns:	
Primary reinforcement	40
Ties, stirrups, spirals	20
Shells, folded plate members:	
ϕ15 bar, W31 or D31 wire, and smaller	10
Other reinforcement.	d_b but not less than 20
In contact with or above sea water	
underside and sides of slab	75
top side of slab	50
beams	75

13.7.3.2 For prestressed concrete members exposed to earth, weather, or corrosive environments, minimum cover shall be increased 50 percent.

13.7.3.3 For prestressed concrete members manufactured under plant control conditions, minimum concrete cover for nonprestressed reinforcement shall be as required in Subclause 13.7.2.

13.7.4 Bundled bars

For bundled bars, minimum concrete cover shall be equal to the equivalent diameter of the bundle, but need not be greater than 50 mm, except for concrete cast against and permanently exposed to earth, minimum cover shall be 70 mm.

13.7.5 Corrosive environments

In corrosive environments or other severe exposure conditions, amount of concrete protection shall be suitably increased, and denseness and nonporosity of protecting concrete shall be considered, or other protection shall be provided.

13.7.6 Future extensions

Exposed reinforcement, inserts, and plates intended for bonding with future extensions shall be protected from corrosion.

13.7.7 Fire protection

When the general building standard requires a thickness of cover for fire protection greater than the minimum concrete cover specified in Clause 13.7, such greater thicknesses shall be according to IPS-E-CE-260.

13.8 For additional information regarding reinforcement details for columns, connections, lateral reinforcement for compression and flexural members, shrinkage and temperature reinforcements and requirements for structural integrity, reference is made to Sections 7.8 through 7.13 of ACI 318M-89.