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*Fifth Revision of*  
**IS 456 Indian Standard Code of Practice  
for Plain and Reinforced Concrete**

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## **Draft IS 456 Structural Concrete**

*Chapter 9*  
**CONSTRUCTION ~~AND QUALITY ASSURANCE~~**

18 September 2022

*CED 2:2 / Panel 5 / Working Group 3 on  
Structural Design Provisions*

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**Bureau of Indian Standards**

Draft IS 456 Structural Concrete Code  
September 2022

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New Delhi



## Chapter 9

# CONSTRUCTION AND QUALITY ASSURANCE

*page*

<b>90.</b>	<b>CONSTRUCTION AND QUALITY ASSURANCE</b>	<b>5</b>
<b>91.</b>	<b>STORAGE OF MATERIALS</b>	<b>6</b>
91.1	Environmental Considerations at the Site	9
<b>92.</b>	<b>STEPS IN CONSTRUCTION</b>	<b>10</b>
92.1	Concrete	11
92.1.1	<i>Formwork</i>	12
92.1.2	<i>Staging</i>	18
92.1.3	<i>Producing</i>	19
92.1.4	<i>Transporting and Handling</i>	24
92.1.5	<i>Placing</i>	26
92.1.6	<i>Compacting</i>	27
92.1.7	<i>Finishing</i>	29
92.1.8	<i>Curing</i>	30
92.1.9	<i>Supervising</i>	33
92.1.10	<i>Concreting in Special Conditions</i>	34
	<i><u>Extreme weather concreting,</u></i>	
	<i><u>Concreting under water</u></i>	
	<i><u>Mass concrete</u></i>	
	<i><u>Concreting in aggressive soils and water</u></i>	
92.2	Reinforcement Steel Bars	64
92.2.1	<i>Cutting</i>	65
92.2.2	<i>Fabricating</i>	66
92.2.3	<i>Assembling</i>	67
92.3	Prestressing Steel Tendons	69
92.3.1	<i>Cutting and Placing</i>	70
92.3.2	<i>Laying in Sheathing Ducts</i>	71
92.3.3	<i>Prestressing</i>	73
92.3.4	<i>Grouting</i>	76
92.3.5	<i>Protecting Post-Tensioned Tendons &amp; Anchorages</i>	80
92.3.6	<i>Prestressing Methods and Arrangements</i>	81
92.4	Untensioned Steel Bars in Prestressed Members	82
<b>93.</b>	<b>QUALITY CONTROL AND QUALITY ASSURANCE</b>	<b>83</b>
93.1	<del>Quality Control</del>	<del>84</del>
93.2	<del>Quality Assurance</del>	<del>85</del>
93.2.1	<del>Levels of Quality Assurance</del>	<del>86</del>
93.2.2	<del>Basic Requirements of Quality Assurance</del>	<del>87</del>
93.2.3	<del>Quality Inspections</del>	<del>90</del>
93.2.4	<del>Sampling and Testing of Concrete</del>	<del>91</del>
93.2.5	<del>Quality Assurance in Concrete Production</del>	<del>96</del>
93.2.6	<del>Quality Assurance in Reinforcement Steel</del>	<del>98</del>
93.2.7	<del>Quality Assurance in Prestressing Steel and Grout Work</del>	<del>99</del>

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	<i>page</i>
<b>94. SPECIAL CONSIDERATIONS</b>	<b>100</b>
94.1 Plain Concrete Structures	101
94.2 Reinforced Concrete Structures	102
94.2.1 Construction Joints	103
94.3 Prestressed Concrete Structures	106
94.3.1 Instability During Erection	107
94.3.2 Hollow Blocks and Formers	108
94.3.3 Precast Joists and Hollow Filler Blocks	109
94.3.4 Jointing of Butted Assemblies	110
94.4 Precast Concrete Structures	111
94.5 Steel-Concrete Composite Structures	112

## **90. CONSTRUCTION AND QUALITY ASSURANCE**

Provisions in this section shall be applicable to construction and Quality Assurance of concrete structures. When new technology *materials, product or process* is introduced in construction, the same shall be subject to *rigorous study* through:

- (1) Detailed experimental work,
- (2) Appropriate analytical work, if relevant, and
- (3) *Rigorous independent third party peer review* panel by subject specialists, each with at least 30 years experience in the subject matter in focus. The review panel shall be appointment duly by the Owner.

(4) specific QA and QC requirements

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## **C90. CONSTRUCTION AND QUALITY ASSURANCE**

The requirement for *rigorous studies* and peer review is motivated by the numerous technologies introduced in the past, which have not been demonstrated to be safe experimentally and/or analytically, and approved by a subject specialist panel.

## 91. STORAGE OF MATERIALS

Stacking and storage of materials (cement, aggregate, steel and other construction materials) at site shall be as per the requirements stated in **IS 4082**.

### (a) Cement

Cement shall be protected during transportation and handling to avoid any deterioration or contamination.

Cement bags shall be:

- (1) Stored on site
  - (a) in a manner so as to avoid deterioration or contamination,
  - (b) in perfectly dry and waterproof sheds, and
  - (c) on platforms that are raised about 0.2 m above ground level, and about 0.6 m clear off the walls;
- (2) Stacked:
  - (a) with not more than 8 bags along the height, and
  - (b) in such a manner as to facilitate their removal and use in the order in which the batches of cement are received.

When cement is stored in *bulk storage containers* (like silos), the following shall be complied with:

- (1) They should be of waterproof and uncracked structure.
- (2) The capacity of the containers shall be sufficient to cater to the requirements of site.
- (3) The containers shall be cleaned at least once in 3 months.
- (4) The cement shall be used in the sequence in which it is received at site (assuming that their manufacture is in the same sequence).
- (5) Each consignment shall be stored separately to readily identify and inspect, when required.
- (6) Any consignment of cement (or a part of it) that has deteriorated in any way during storage shall not be used in works, and shall be removed immediately from site.
- (7) Cement shall be used within 3 months or date of expiry specified by the manufacturer, whichever is earlier.

### (b) Aggregates

Fine aggregates and coarse aggregates shall be stacked separately on hard well-drained surfaces or platforms, such that the stockpiles are sufficiently away from each other.

When aggregates are placed directly on hard ground, only that material which is 0.3m above ground level shall be initially taken out and used. The remaining material shall be used only after it has been fully cleaned.

### (c) Reinforcing Steel

Reinforcement bars shall be:

- (1) Stored in dry covered sheds and on platforms, skids or other supports, which are raised about 0.15 m above ground level, and about 0.3 m clear off the walls;
- (2) Stored separately according to their classification, size and lengths; and
- (3) Given a coat of protective cement wash, preferably at all sites, but necessarily in coastal areas or when stored for long.

### (d) Prestressing Material

All prestressing material (*e.g.*, steel tendons, sheathing, anchorages, sleeves or couplers) shall be protected during transportation, handling and storage to avoid any damage or deterioration.

Prestressing steel shall be:

- (1) Absolutely clean and without any signs of rust and
- (2) Stored:
  - (a) In dry covered sheds with instruments capable of measuring air humidity,
  - (b) On platforms, skids or other supports, raised about 0.15 m above ground level, and about 0.3 m clear off the walls;
  - (c) Wrapped with protective covering of tar paper or polythene or any other approved material;
  - (d) Separately according to their classification, size and lengths.

Tendons shall:

- (1) Be protected from:
  - (a) Splashes from any other material,
  - (b) Cutting operation of oxy-acetylene torch or arc welding processes in the vicinity, or
  - (c) Site heat treatment or welding operation, or metallic coating such as galvanising.
- (2) Not be kinked or notched during transportation and storage.
- (3) Be stored in large diameter coils, which enable tendons to be laid out straight. As a guide wires above 5mm diameter, coils of about 3m diameter shall be obtained from manufacturer.
- (4) Wrapped with protective sheeting that is chemically neutral.
- (5) Be provided with temporary protection during storage.

**(e) Anchorage Components**

All components shall be:

- (1) Handled and stored to prevent mechanical damage and detrimental corrosion.
- (2) Prevented from any type of corrosion to gripping and securing systems.
- (3) Used with such formulated oils and greases, which are guaranteed by the manufacturer to be non-aggressive and non-degrading.

The above provisions are reproduced from IS 4082 in IS456:2000.

It is proposed that all provisions of IS 4082 be moved here, and IS 4082 withdrawn.

Requirements for stacking and storage of constituent materials of *Self-Compacting Concrete* (SCC) shall be the same as that for materials for conventional concrete. In addition, the following requirements shall be complied with:

- (1) Storage of aggregates shall be such that:
  - (a) Cross-contamination is avoided of different types and sizes of aggregates;
  - (b) They are placed in a room or chamber, which is protected from fluctuations in the weather; and
  - (c) When stored in open ground, they are placed in specially-built partitioned bays, which allow free drainage of excess moisture in the aggregates and rainwater.
- (2) Storage of reinforcement bars shall be such that the bars are protected from exposure to saline atmosphere during storage, fabrication and use.

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### C9i. STORAGE OF MATERIALS

**IS 4082** provides general guidance for stacking and storage of materials at site and covers cement, aggregate, steel and other construction materials.

Storage of cement in silos is not mentioned in **IS 4082**. But, if silos are used, they should be of waterproof and crack proof construction. **IS 8043** is permitted by the Code where cement is to be stored for prolonged periods.

The said stacking of coarse aggregates is recommended to prevent:

- (1) Mixing up with soil, and
- (2) Material at the edges of the piles from getting inter-mixed.

The said stacking of reinforcement bars is recommended to avoid:

- (1) Mixing up with soil, and
  - (2) Corrosion,
- and thereby protect them from exposure to saline atmosphere during storage, fabrication and use.

SCC mix is more sensitive to variations. Hence, the special precautions are added to minimize the fluctuation of surface moisture content and movement of fines.

#### **91.1 Environmental Considerations at the Site**

Suitable measures, including the following, shall be employed:

- (a) Store cement and other fine powders in closed rooms and bins, and carry them in closed containers during transportation.
- (b) Sprinkle water on fine aggregates.
- (c) Batch and mix concrete in closed containers.
- (d) Regularly monitor the quality of run-off water from the *batching plants, mixing chambers* and *construction sites*.

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#### **C91.1 Environmental Considerations at the Site**

The provisions are meant to avoid pollution arising from *storage* of materials, and from *production and use* of concrete. The provisions help in:

- (a) Preventing any fine particulate material from getting airborne and being inhaled by humans and animals;
- (b) Keeping the fine aggregates in a slightly damp state to prevent their particles from getting airborne; and
- (c) Ensuring its safe disposal.

**92. STEPS IN CONSTRUCTION**

While the construction sequence of a project is detailed and has many activities performed in parallel, the provisions provided hereunder shall be followed with regard to the said activities related to each material.

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**C92. STEPS IN CONSTRUCTION**

These steps in construction related to materials are based on engineering principles and past experience.

### **92.1 Concrete**

Concrete shall be *handled, held in position, placed, finished and cured* as per provisions indicated hereunder.

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### **C92.1 Concrete**

Green concrete has time dependant properties, which depend on how it is *handled, held in position, placed, finished and cured*. To ensure good quality control in all concrete structures, these operations are standardised.

**92.1.1 Formwork**

The formwork shall be designed and constructed so as to:

- (1) Remain sufficiently stiff during placing and compaction of concrete, and
- (2) Prevent loss of slurry from the concrete.

Reference may be made to **IS 14687** for details on basic requirements, design and detailing of formwork. The provisions provided hereunder are in addition to those specified in **IS 14867**.

The tolerances on the shapes, lines and dimensions of formwork for different levels of quality control shall be within the limits specified in **Table 9.1**. Variations shall be measured from 0 level. These tolerances apply only to external dimensions of concrete members and not to the positioning of reinforcing steel within them or dowels protruding from them.

**Table 9.1:** Permitted maximum deviation in shapes, lines and dimensions of Formwork

Component of Concrete Structure	Level of Quality Control (mm)		
	QA31	QA2	QA13
<b>Wall</b>			
Verticality up to 2m	± 4	± 10	± 15
Verticality up to 3m	± 6	± 12	± 20
Verticality up to 7m	± 8	± 15	± 25
Verticality up to 10m	± 10	± 20	± 25
Straightness in 5m length	± 3	± 6	± 10
<b>Column</b>			
Verticality up to 3m	± 5	± 10	± 15
Verticality up to 7m	± 7	± 12	± 20
Verticality up to 20m	± 10	± 20	± 25
Cross section up to 300 mm	± 2	± 3	± 5
Cross section 300 to 600 mm	± 3	± 5	± 10
Cross section 600 to 1.5 m	± 4	± 10	± 15
Squareness	3	6	10
<b>Beam</b>			
Depth up to 300 mm	± 3	± 3	± 8
Depth up to 600 mm	± 4	± 8	± 15
Depth over 600 mm	± 5	± 10	± 20
Variation in datum	± 5	± 10	± 10
Straightness in 5m Length	± 3	± 8	± 12
<b>Soffits</b>			
Flatness on 2.5m grid	± 9	± 15	± 20
Variation in datum	± 8	± 10	± 15
<b>Footings</b>			
	Deviation from dimensions		
Plan Dimensions	+50 mm and -10 mm		
Eccentricity	0.02 times the width of the footing in the direction of deviation, but not more than 50 mm		
Thickness	+50 mm and -10 mm, or ± 0.05 times the specified thickness, whichever is less		

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Where the shape of the element is such that the formwork has re-entrant angles, the formwork shall be removed as soon as possible after the concrete has set, to avoid shrinkage cracking occurring due to the restraint imposed.

The formwork shall be:

(1) Designed and constructed so as to remain sufficiently stiff during placing & compacting concrete, and

(2) Such as to prevent loss of slurry from the concrete.

The design and detailing of formwork shall be as specified in **IS 14687**. The tolerances on the shapes, lines and dimensions shown in the drawing shall be within the limits given in **Table 9.2**. These tolerances apply to concrete dimensions only, and not to positioning of vertical reinforcing steel bars or dowels.

**Table 9.2:** Tolerances in Formwork used in construction of concrete structures

S.No.	Measurement	Amount (mm)
1	Deviation from specified dimensions of cross-sections of columns and beams	+ 12 mm
		- 6 mm
2	Deviation from specified dimensions of footings	
	(a) Dimensions in plan	+ 50 mm
		- 12 mm
	(b) Eccentricity	0.02 times the width of the footing in the direction of deviation, but not more than 50 mm
	(c) Thickness	±0.05 times the specified thickness

All rubbish, particularly, chippings, shavings and sawdust shall be removed from the interior of the forms before the concrete is placed. The face of formwork in contact with the concrete shall be cleaned and treated with form release agent. Release agents shall be applied so as to provide a thin uniform coating to the forms without coating the reinforcement.

In PSC structures, moulds for pre-tension members shall be sufficiently strong and stiff to withstand (*without distortion*) the effects of placing and compacting concrete as well as those of prestressing in the case of manufacture by the individual mould process, where the prestressing tendon is supported by the mould before transfer.

**(b) Stripping Time**

Forms shall not be released until the concrete has achieved *strength* of at least *twice* the stress to which the concrete may be subjected at the time of removal of formwork. The strength referred to shall be that of concrete using the same cement and aggregates and admixture, if any, with the same proportions and cured under conditions of temperature and moisture similar to those existing on the work.

To achieve the above criterion of *strength*:

- (1) While the above criteria of strength shall be the guiding factor for removal of formwork, in normal circumstances, where ambient temperature does not fall below 15°C and where *Ordinary Portland Cement* is used and adequate curing is done, the striking period specified in **Table 9.3** may deem to satisfy the above guideline. In structures made of other cements and when temperature at the site is low, the stripping time recommended shall be modified suitably.
- (2) The number of props left under, their sizes and disposition shall be such as to safely carry the full *Dead Load* of the slab, beam or arch, as the case may be, together with any *Imposed Load* likely to occur during curing or further construction.
- (3) Where the shape of the element is such that the formwork has re-entrant angles, the formwork shall be removed as soon as possible after the concrete has set, to avoid shrinkage cracking occurring due to the restraint imposed.

The blue highlighted clauses are reproduced from IS 14687.

The **Table 9.3** is updated.

**Table 9.3:** Minimum period before striking formwork in construction of concrete structures

S.No.	Type of Formwork	Minimum Duration before stripping of Formwork of Concrete Structures made using	
		OPC	Cement other than OPC, or Cementitious Materials like Fly Ash & Slag
1.	Vertical formwork to columns, walls & beams	16-24 hours	16-24 hours
2.	Soffit formwork to slabs (Props to be re-fixed immediately after removal of formwork)	3 days	7 days
3.	Soffit formwork to beams (Props to be re-fixed immediately after removal of formwork)	7 days	10 days
4.	Props to slabs: (a) Spanning up to 4.5 m (b) Spanning over 4.5 m	7 days 14 days	10 days 14 days
5.	Props to beams & arches: (a) Spanning up to 6 m (b) Spanning over 6 m	14 days 21 days	14 days 21 days

After *stripping*, utmost care shall be taken to provide props. These props shall be provided immediately after stripping each shuttering panel and not after stripping all the panels of the entire slab.

When concrete structures are made with cements other than OPC or cementitious materials, the stripping of formwork may be done as per the minimum duration of stripping of formwork for concrete structures made using OPC given in **Table 9.3**, provided the compression test to obtain compressive strength on cubes and to obtain bending tensile strength on flexure specimen indicate that at least the minimum strengths specified in **Table 9.4** are achieved in concrete. At least three specimens shall be considered for each of these two tests.

**Table 9.4:** Minimum strength before *Stripping* of the Formwork in concrete structures are made with cements other than OPC or cementitious materials

S.No.	Age (days) of Cubes at the time of Test	Percentage of Specified Strength
1	3	45%
2	7	60%
3	14	85%

**Add:**

Different requirements for different grades of concrete, *i.e.*, low grades (M40 and lesser), and higher grades (higher than M40).

### C92.1.1 Formwork

#### (a) Formwork

Tolerances on the dimensions of the structures are a practical necessity. Design provision accommodates some of these tolerances. For example, the partial safety factor  $\gamma_M$  for concrete is taken as 1.5 in the *Limit State Method*, and minimum eccentricity of load is specified for columns. Tolerances for construction of formwork given in this clause are not to be taken as tolerances on constructed structures for which this standard does not give any requirement. The tolerances for placing reinforcements are given separately (Figure C9.1). The vibration effect should be taken into account invariably in the design of formwork.

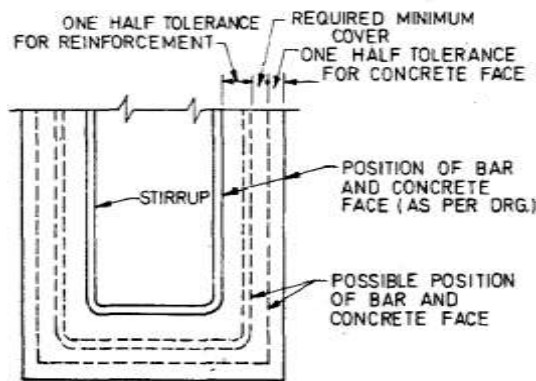


Figure C9.1: Bending dimension for stirrups in concrete structures

It should be ensured that formwork is erected with joints tight enough to prevent leakage of cement mortar. Surfaces that are to come in contact with fresh (*wet*) concrete should be treated by coating with a non-staining mineral oil or any other approved material. Where formwork absorbs water from concrete, they should be thoroughly wetted to: (i) prevent absorption of water from green concrete, and (ii) ensure easy release and non-adhesion to formwork during stripping.

#### (b) Stripping Time

Stripping time of horizontal formwork should be the time to achieve 66.6% of compressive and tensile strength for the grade of concrete used in construction. This should be confirmed by the destructive tests on concrete cubes or concrete beams, as the case may be, for the batch of concrete. Only after confirmation from the test, should the formwork be stripped. While stripping time of formwork for indicated in the clause applies to OPC, when other cements (especially Rapid Hardening Cement, Low Heat Portland Cement, or Pozzolana-based Cements) are used stripping time of horizontal formwork shall be the time to achieve 66.67% of compressive and tensile strength for the grade of concrete used in construction. The values provided in Table 9.4 shall be used when actual values are not possible, only after the Engineer-in-Charge is satisfied that these values are reasonable.

In some cases, such as while using cements other than *Ordinary Portland Cement* or when the curing conditions are not normal, it may be necessary to estimate the strength of concrete at the time of removal of formwork. Cubes cast to determine the strength of concrete at the time of removal of formwork, should be cured along with the structure and not under standard conditions.

Accordingly, these cubes should not be used for the acceptance of concrete. For rapid hardening cement,  $3/7$  of the periods given for *Ordinary Portland Cement* will be sufficient normally, except that a minimum period of 24 hours is required. It should be ensured that formwork is removed carefully, so that shock and damage to the concrete are avoided. Also, due regard must be given to curing methods to be employed before the formwork is removed.

### 92.1.2 Staging

The props placed under members that they are supporting (*e.g.*, slab, beam or arch) shall be designed (through their *number, size* and *material strength* as per suitable Indian Standards) such that their:

- (1) Stiffness does not result in more than **2 mm** vertically at the bottom forms they are propping;
- (2) Strength makes them capable of carrying **full dead load** of member they are supporting and any **live load** likely to occur on the members during curing or further construction; and
- (3) *Base plates* (underneath them) are rested on competent *ground* or *structural floor*, which has sufficient bearing strength on the day of loading of the prop.

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### C92.1.2 Staging

The props should not jeopardize the intents of formwork, namely adequate stiffness and sufficient strength. In particular, a prop should not:

- (1) *Deform* to the extent that they distort the geometry of the member it is supporting, and help retain the intended geometry of the supported member;
- (2) *Fail* to carry loads expected on itself, thereby jeopardizing the intent of formwork; and
- (3) *Cave in* to the ground underneath or *fail* in local bearing, by puncturing into the ground or structural floor they are rested on, again jeopardizing the intent of formwork.

### 92.1.3 Producing

The provisions hereunder shall be complied with during *batching, mixing and measuring* of concrete.

#### (a) Batching

In batching concrete, the quantities of all ingredients of concrete shall be determined only by *weigh-batching*, as given below:

- (i) *Cement and Aggregates* : by *Mass*; and
- (ii) *Admixtures* : by *Mass*, if admixture is solid, and *volume* if it is liquid.

For grades of concrete up to M20, *volume batching* of cement and aggregate may be allowed, provided:

- (i) *Weigh-batching* is not practical, and
- (ii) *Accurate bulk densities have been pre-established* of materials to be actually used in concrete.

But, in such cases, allowance for bulking shall be made in accordance with IS 2386 (Part 3). The mass volume relationship should be checked as frequently as possible preferably everyday, the frequency for the given job being determined by engineer-in-charge to ensure that the specified grading is maintained.

For large and medium project sites, concrete shall be sourced from *ready-mixed concrete plants* or from *captive on-site or off-site automatic batching & mixing plants*. The quality control of concrete produced and supplied by either of these plants shall be in accordance with IS 4926.

Further:

- (1) The practical number of different concrete mixes shall be kept small on any site or in any one plant.
- (2) Grading of aggregate shall be controlled by obtaining coarse aggregate in different sizes and blending them in right proportions. Aggregates of different sizes shall be stocked in separate stock-piles. Material shall be stock-piled for several hours of production, preferably *a day* before use. Grading of coarse and fine aggregate shall be checked as frequently as possible, the frequency for a project being determined by the *Engineer-in-Charge* to ensure that the specified grading is maintained.
- (3) Accuracy of the measuring equipment shall be within  $\pm 2\%$  of the quantity of cement being measured and within  $\pm 3\%$  of the quantity of aggregate, admixtures and water being measured. In a batching plant, the concrete producing equipment shall be calibrated *initially* at the time of installation or re-conditioning of the equipment, and *subsequently* at the following intervals:
  - (a) *Mechanical/knife edge systems*: At least once every 2 months
  - (b) *Electrical/load cell systems*: At least once every 3 months
  - (c) *Probes for Moisture Content*: At least once every 2 months
- (4) Proportion, type and grading of aggregates shall be made by trial in such a way so as to obtain densest possible concrete.
- (5) Water-cement ratio specified shall be maintained constant at its design value. To this end, moisture content in both fine and coarse aggregates shall be determined as frequently as possible, the frequency for a project being determined by the *Engineer-in-Charge* according to weather conditions. Amount of the added water shall be adjusted to compensate for any observed variations in the moisture contents. Moisture content in aggregates shall be determined as per IS 2386 (Part 3). Also, suitable adjustments shall be made in the masses of aggregates to allow for variation in mass of aggregate due to variation in their moisture content. In the absence of exact data, only in the case of *Nominal Mixes*, the amount of surface water may be estimated from the values given in Table 9.5.
- (6) No substitutions shall be made of materials used on the project or alterations made in the established proportions, except as permitted in Clause 92.1.3.(a)(5), without additional tests to show that the quality and strength of concrete are satisfactory.

**Table 9.5:** Surface Water Carried by Aggregate

S.No.	Aggregate	Approximate Quantity of Surface Water	
		Percentage by Mass	Liters/m <sup>3</sup>
1	Wet Sand	7.5	120
2	Moderately Wet Sand	5.0	80
3	Moist Sand	2.5	40
4	Moist Gravel or Crushed Rock	2.5 - 1.25	40 - 20

**(b) Mixing**

Concrete shall be mixed only by mechanical methods (and not by hand mixing), either in a mechanical mixer or in a batching and mixing plant complying with **IS 1791**. It shall be ensured that stationary, central and truck mixers comply with the performance criteria of mixing efficiency laid down in **IS 12119**. Mixing efficiency test shall be performed at least once in a year for each mixer. The mixers shall be fitted with water measuring (metering) devices.

The mixing shall be continued until:

- (1) There is a uniform distribution of the materials;
- (2) The entire mass of concrete is uniform in colour and consistency; and
- (3) Each individual coarse aggregate is coated completely with of mortar containing its proportionate amount of cement.

If there is segregation after unloading from the mixer, the concrete should be re-mixed immediately, if there is sufficient time to allow for placing and compacting before the initial set time, else discarded.

Further:

- (1) The mixing time shall be at least **2 min** for conventional free fall (drum) batch type concrete mixers. For more efficient mixers, manufacturers' recommendations shall be followed.
- (2) Workability should be checked at frequent intervals (**IS 1199**).
- (3) Dosages of retarders, plasticizers and superplasticizers shall be arrived based on requirement of *workability, setting time and early strength*. The maximum limit shall be as per manufacturer's recommendation. Dosages of retarders, plasticizers and superplasticizers shall be restricted to 0.5%, 1.0% and 2.0%, respectively, by mass of cementitious materials, unless a higher value is agreed upon between the manufacturer and the constructor based on performance test.
- (4) The mixer and plant shall be approved by *Engineer-in-Charge*. The mechanical mixer shall be fitted with a water measuring (metering) device. The mixer or plant shall be at a location approved by the *Engineer-in-Charge*, considering the properties of mixes and the transportation arrangements available with the contractor.
- (5) Mixers that have been out of use for more than 30 minutes shall be thoroughly cleaned before putting in a new batch.
- (6) Unless otherwise agreed by the *Engineer-in-Charge*, the first batch of concrete from the mixer shall contain only *two thirds* of the normal quantity of coarse aggregate.
- (7) Mixing plant shall be thoroughly cleaned before changing from one type of cement to other.

Further:

- (1) *For projects requiring using less than 20 tons of cement for producing concrete per day:*

Small (1 bag) concrete mixer that is diesel or electric operated, with minimum size of 40 liter automatic water measuring and dispensing system with diesel or electrically operated lift for vertical transport of concrete, or supply by RMC plant including transportation, delivery, supply and pumping of concrete;

- (2) *For projects requiring using around 75 tons of cement for producing concrete per day:*

Batch-type concrete mixer diesel or electric operated, with minimum size of 200 liters, automatic water measuring system and integral weigh-batcher (hydraulic or pneumatic type); and

(3) For projects requiring using around 175 tons of cement for producing concrete per day:

Concrete batching and mixing plant fully automatic with minimum capacity of 15 m<sup>3</sup> per hour or higher as per requirement.

**(c) Measuring Concrete**

All measuring devices of the equipment shall be maintained in clean and serviceable condition. Its accuracy shall be checked over the range in use, immediately when installed at a site and periodically thereafter as directed by *Engineer-in-Charge*. The accuracy of such measuring devices shall fall within the following limits of the quantity of material measured in each batch:

- (1) Cement:  $\pm 3\%$
- (2) Water :  $\pm 3\%$
- (3) Aggregate :  $\pm 3\%$
- (4) Admixture :  $\pm 5\%$

**C92.1.3 Producing**

The clause requires automation to be adopted liberally in the construction involving concrete structures. It mentions specifications for equipment that produce and measure concrete.

**C(a) Batching**

Small number of mixes at a project site will avoid confusion and error in batching. **IS 4925** gives the specification of batching and mixing plant for concrete. Usually, these plants are designed specially to suit the local conditions and output required. Small plants may have an output of mixed concrete as low as 30 m<sup>3</sup>/hour, medium plants in the range of 100–300m<sup>3</sup>/hour and large plants over 300 m<sup>3</sup>/hour. **IS 4925** covers the requirements of manual, semi-automatic or fully automatic central batching and mixing plants capable of producing not less than 100 m<sup>3</sup>/hour of mixed concrete.

Allowance for bulking of sand is necessary only in volume batching. But, allowance for surface water carried by the aggregate should be made in all cases. **IS 2386 (Part 3)** gives a field method for determination of necessary adjustment of bulking of fine aggregate, as the sand may contain an amount of moisture, which will cause it (sand) to occupy a larger volume than it would occupy when dry. If sand is measured by loose volume, it will be necessary to increase the quantity, so that the amount of sand put into the concrete may be the amount intended for the nominal mix used (based on dry sand). It is necessary to increase the volume of sand by the percentage of bulking. The correction will be approximate only, because the measurement of volume of loose sand is a rough method (at best), but a correction of the right order can easily be determined. Based on the fact that the volume of the inundated sand is the same as for dry sand, two methods are suggested in **IS 2386 (Part 3)**.

A field method for determination of surface moisture in fine aggregate is also given in **IS 2386 (Part 3)**. The accuracy of the method depends on the accuracy of information on the specific gravity of the material in a saturated surface-dry condition. The standard suggests that the same procedure, with appropriate change in the volume of the sample and the dimension of the container used for the test, to be applied to coarse aggregates as well. Coarse aggregates carry less surface water.

Thus, the provisions help in the following ways:

- (1) Avoid confusion and error in batching,
- (2) Ensure continuous supply of concrete for the project in focus, and
- (3) Ensure quantities of ingredients consistent with the desired mix.

**C(b) Mixing**

**IS 1791** lays down requirements regarding the drum, water tanks and fittings, loaders, hoppers, power units, discharge height and roadworthiness for the free fall (drum) batch type concrete mixers. The continuous mixer, forced action (pan) type mixer and truck mounted mixer are not covered by this standard. Strictly speaking, there should be no bar in using the latter type of mixers, but the clause draws attention only to the more common type of mixer (that is, drum type mixer) used at site, for which an Indian Standard is available. Pan type mixers are used more often in precast concrete factories, and truck mounted mixers for ready mixed concrete.

**IS 4634** gives the method of testing the performance of batch type concrete mixers in terms of uniformity of constituents in the concrete mix. The mixing efficiency, *i.e.*, an index of the uniformity of the mixed concrete, can be evaluated by finding the percentage variation in quantity of cement, fine aggregate and coarse aggregate in a freshly mixed batch of concrete. According to **IS 1791**, the percentage variation between the quantities of cement, fine aggregate and coarse

aggregate (as found by weighing in water) in the two halves of the batch and the average of the two halves of the batch should not exceed the following limits:

- (a) Cement : 8%
- (b) Fine aggregate : 6%
- (c) Coarse aggregate : 5%

#### 92.1.4 Transporting and Handling

After mixing, concrete shall be transported to the formwork as rapidly as possible by methods which will prevent the segregation or loss of any of the ingredients or ingress of foreign matter or water and maintaining the required workability.

- (1) In general, concrete shall be discharged from the truck-mixer within 2 h of the time of loading.
- (2) Longer duration of discharge of concrete may be permitted, if retarding admixtures are used or in cool humid weather or when chilled concrete is produced.

The time of loading shall be measured from *mixing water to dry mix of cement & aggregate*, or from adding *cement to wet aggregate*, whichever is applicable.

During hot or cold weather, concrete shall be transported in deep containers. Other suitable methods to reduce the loss of water by evaporation in hot weather and heat loss in cold weather also may be adopted.

When ready-mix concrete is used, an additional dose of admixtures may be added to the concrete, such that:

- (1) The total dosage of the admixture does not exceed the maximum recommended dosage for that admixture; and
- (2) Sufficient trials have been carried out to ensure the performance of the concrete after such re-dosing.

Sufficient number of rotations of the transit mixer must be carried out at mixing RPM so as to ensure a homogenous mixing of the re-dosing admixture.

Unless otherwise specified, the equipment used for transportation and compaction of concrete shall meet the following requirements:

##### (a) Transporting and Producing Concrete

The equipment used in transporting concrete shall include:

- (1) Concrete dumper of at least 2 Tonne capacity,
- (2) Powered hoist of at least 0.5 Tonne capacity,
- (3) Chutes,
- (4) Buckets handled by cranes,
- (5) Transit truck mixer,
- (6) Concrete pumps,
- (7) Concrete distributor booms,
- (8) Belt conveyors,
- (9) Crane with skips, and
- (10) Tremies.

##### (b) Compacting Concrete

The equipment used in compacting concrete shall include:

- (1) Internal vibrators of sizes 25mm to 70mm,
- (2) Form vibrators of at least 500W, and
- (3) Screenshot vibrators, whose width is changed as per requirement.

**C92.1.4** *Transporting and Handling*

Segregation of concrete occurs because concrete is a mixture of materials differing in particle size and specific gravity. Any lateral movement that occurs when concrete is being deposited at one point and allowed to flow within the forms, or when the concrete is projected forward by the conveying equipment, causes the coarse aggregate and mortar to separate. Segregation may easily occur unless special attention is given to its prevention. When stiff concrete is transferred from one conveyance to another, long unconfined drops should be avoided, rather the use of hoppers; baffles and short vertical drops through a pipe, to the centre of the receiving container is recommended.

Again, the clause requires automation to be adopted liberally in the construction involving concrete structures. It mentions specifications for equipment that transport, place and vibrate concrete.

### 92.1.5 *Placing*

Concrete shall be deposited as close as practicable to the member being concreted to avoid re-handling. The concrete shall be placed and compacted before initial setting of concrete commences, and shall not be subsequently disturbed. Methods of placing shall be such as to preclude segregation. Care shall be taken to avoid displacement of reinforcement or movement of formwork. In general, concrete shall be placed gently, and the maximum permissible free fall of concrete shall be limited to 1.5 m.

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### C92.1.5 *Placing*

Concrete should be deposited at or near its final position in the placement, eliminating the tendency to segregate when it has to flow laterally into its place. On sloping surfaces, concrete should be placed at the lower end of the slope first, progressing upward, and thereby increasing natural compaction of the concrete. High velocity discharge of concrete, which may cause segregation of the concrete, should be avoided. Recommended methods of placing concrete in segregation prone location are:

#### (a) **Narrow Forms**

Concrete should be discharged first into a light hopper fitted with a light, flexible drop chute, so that concrete is placed at the surface without striking at the formwork or reinforcements. This avoids segregation and leaves the formwork and reinforcements clean until concrete covers them. If wet concrete is to be placed in narrow, deep formwork, water content in the upper layers should be gradually reduced to compensate for the water gain.

#### (b) **Through Side Ports in Column Formwork**

Concrete should be dropped vertically into the outside pockets under each formwork opening (port), so that concrete stops and then flows easily into the column formwork.

#### (c) **Sloping Surface**

Concrete should not be discharged from free end of a chute on to a sloping surface, as the heavier coarse aggregates are separated and carried down the slope. The chute should be fitted with a baffle and a drop at its end, so that concrete remains on slope. Concrete should not be placed on sloped surfaces unless the concrete is fully contained within formwork and the concrete can be compacted by vibration.

#### (d) **Use of Wheel Barrows**

Concrete from wheel barrows should not be dumped away from the face of concrete already in place. It should be dumped into the face of concrete already in place.

#### 92.1.6 Compacting

Concrete shall be thoroughly *compacted*, and the vibrator *worked fully* around the reinforcement, around embedded fixtures and into corners of the formwork.

Concrete shall be compacted using mechanical vibrators complying with **IS 2505, IS 2506, IS 2514** and **IS 4656**. *Over-vibration* and *under-vibration* of concrete are harmful and shall be avoided. Also, vibration of *very wet mixes* shall be avoided. Whenever vibration has to be applied externally, the design of formwork and the disposition of vibrators shall receive special consideration to ensure efficient compaction and to avoid surface blemishes.

The concrete used shall have adequate workability that can be properly compacted by means of internal vibration. Adequate compaction shall be ensured by providing suitable workability and by employing appropriate placing and compacting equipment and procedures. Full compaction shall be ensured in the vicinity of: (a) construction and movement joints, (b) embedded water bars and reinforcement, (c) tandems or duct formers, (d) embedded fixtures, and (e) corners of formwork, to produce a dense homogeneous void-free mass having the required surface finish.

When vibrators are used, vibration shall be done continuously during the placing of each batch of concrete until the expulsion of air has practically ceased and in a manner that does not promote segregation. Over vibration shall be avoided to minimize the risk of forming a weak surface layer.

When external vibrators are used, the design of formwork and access of vibrator shall be such as not to be applied through reinforcement and all inserts (like ducts). Internal vibrations shall be inserted in an orderly manner and the distance between insertions vibrators shall be about one and half times the radius of the area visibly affected by vibration. Additional vibrators in serviceable condition shall be kept at site so that they can be used immediately in the event of break-down of one.

Mechanical vibrators shall comply with **IS 2502, IS 2506, IS 2514** and **IS 4656**.

### C92.1.6 Compacting

The clause recommends mechanical methods of vibration. Immersion vibrators (IS 2505) are used for consolidation of plain as well as reinforced concrete. They can be either: (a) flexible shaft type, powered by different types of motors; or (b) motor-in-head type, electrically or pneumatically driven. The operational frequency of the vibrator should be preferably in the range 8,000–12,000 vibrations per minute. While compacting with internal vibrators, concrete should be deposited in layers of 30 to 45 cm thick and the vibrator inserted vertically at uniform spacing over the entire area of placement. The vibrator penetrates rapidly to the bottom of the layer and at least 15 cm into the preceding layer, if any. It should be held (generally 5 to 15 seconds) until the compaction is considered adequate and then withdrawn slowly at the rate of about 8 cm per second.

Concrete vibrators of screed board type (IS \_\_\_\_\_) are suitable for compaction of concrete roads, runways, floors, pavements and thin slabs, where the area to be compacted is large or the thickness is too small (less than 200 mm). They exert their effects at the top surface and compact the concrete from the top down. The screed vibrator consists of a screed board or plank long enough (generally 3 m or 5 m) to span the width of the slab. One or more eccentrics, depending on the length of the screed, are attached to the top. The eccentrics are driven by suitable power units. Usually, the vibrator is provided with two handles, fitted with anti-vibration packing or springs. An anchor, capable of being embedded into ordinary ground temporarily, is mounted on to one of the handles. The recommended minimum frequency under no-load state is 3,500 vibrations per minute, the amplitude not less than 1.5 mm.

Formwork vibrators (IS 4656) are used for compaction of concrete in precast concrete moulds, such as pipes, gullies and deep post-tensioned beams. Also, they are used for compaction of *in-situ* concrete in small and narrow sections or very heavily reinforced sections where immersion vibrators cannot be used. They are powered by electric or air motor and are of two types, namely: (a) the fixed or clamp type, and (b) the manual type. The clamp type is more widely used, and the manual type is used in situations where there are no means of fitting the clamps or where continuous movement along the formwork is desirable. The frequency of vibration under no-load (operation in air) should not be less than 2,800 vibrations per minute for both types of formwork vibrators and the acceleration of vibration under loaded state should not be less than 3g.

Vibrating Table (IS 2514) are used for compaction of concrete in moulds for the manufacture of precast products and structural, elements. They compact concrete through rapidly alternating horizontal, vertical or circular vibrations which are transmitted to moulds filled with concrete and placed or clamped on the table top. They are to be distinguished from shock tables which pulsate at low frequency and operate on the principle of gravity fall with the help of rotating cans. Usually, they have a breadth of 1m and length varying from 1-3 m. The frequency of vibration for the table operating at its maximum load capacity should be between 3,000-6,000 vibrations per minute, and vibration acceleration should not be less than 4g. Under-vibration being harmful should be avoided. Over-vibration can occur if, due to careless operation or use of grossly oversized equipment, vibration is many times the desirable amount. This over-vibration may result in one or any combination of the following damages:

- (a) Settlement of coarse aggregate-This condition is more likely to occur with wet mixes and where there is a large difference in specific gravity between the coarse aggregate and mortar.
- (b) Sand streaks: heavy bleeding of the concrete along the formwork. They are most likely to occur with the use of harsh, lean mixes.
- (c) Excessive formwork deflection or formwork damage - These are most likely when used with external vibration or when arrangement of holding the formwork in place is improper.

Good compaction will prevent segregation from occurring.

#### 92.1.7 Finishing

After compaction, the operations of *screeding*, *floating* and *first troweling* shall be performed to obtain a durable surface. The process of finishing operation from *floating* to *troweling* shall be delayed as long as possible, while still working toward the desired grade and surface smoothness. Over-manipulation of the concrete shall be avoided to control the deposition of excessive fines and water at the surface.

During or after finishing operations, *free water* will not accumulate at the surface of concrete, if proper *consistency* and *design mix proportions* are used. If it does, the same shall be removed by *blotting* with absorbing mats, draining or pulling off with a loop of hose so that the surface loses its water sheen before the next finishing operation is performed. Under *no circumstance*, any finishing tool shall be used in an area with accumulated water, before removing the same.

Surface shall not be overworked on. Also, addition of water or cement to aid in finishing shall be avoided.

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#### C92.1.7 Finishing

Good finishing practices are essential for durable concrete. But, adding water or cement results in laitance, which will impair strength and durability of the member, and make it vulnerable to freezing and thawing under wet conditions. A layer of water develops at the top of freshly placed concrete by settlement of solid particles of cement and aggregate and simultaneous upward migration of water. A small amount of bleeding is normal and will not affect the durability or strength of concrete. Excessive bleeding can result in high water-cement ratios that can cause durability and surface strength problems. Finishing should be performed after the presence of bleed water is gone. Use of properly graded aggregate and proper dosage of cementitious materials will reduce bleeding to an acceptable level.

Over-manipulation of the concrete will lessen the quality of finished surface, causing checking, crazing and dusting.

**92.1.8 Curing**

The curing regime shall prevent the development of high temperature gradients within the concrete. The surface shall be kept moist for at least seven days, when super-sulphated cement concrete is used.

Concreting operations shall commence only after the Contractor has made adequate arrangements for curing. Curing and protecting concrete shall start immediately after compaction of the concrete.

**(a) Normal Curing**

Curing shall be performed either by *Moist Curing* or by *Membrane Curing*, in both *Normal* and *High Strength Concretes*.

**(1) Moist Curing:**

Exposed surfaces of concrete shall be kept continuously in a damp or wet condition by ponding or by covering with a layer of sacking, canvas, hessian or similar materials, and kept constantly wet for at least:

- (i) 7 days from the date of placing concrete, when *Ordinary Portland Cement* is used,
- (ii) 10 days from the date of placing concrete, when exposed to dry and hot weather conditions, and
- (iii) 14 days from the date of placing, when *Cements with Mineral Admixtures* or *Blended Cements* are used.

**(2) Membrane Curing:**

- (i) Approved curing compounds shall be used in lieu of *Moist Curing* with the permission of the *Engineer-in-Charge*. Such compounds shall be applied to all exposed surfaces of concrete as soon as possible after the concrete has set.
- (ii) Impermeable membrane (e.g., polyethene sheeting covering closely the concrete surface) also may be used to provide effective barriers against evaporation.

When adopting *Membrane Curing* for the concretes containing *Portland Pozzolana Cement*, *Portland Slag Cement* or *Mineral Admixture Cement*, the duration of curing shall be increased.

**(b) Steam Curing**

It shall be ensured that Steam Curing is done in a suitable enclosure to contain the live steam to minimize moisture and heat losses. Steam shall be at 100% relative humidity. Steam shall not be applied directly on the concrete surface.

The following schedule shall be adopted for Steam Curing:

- (1) Steam Curing shall be started only after about 4 hours of placement of concrete to allow the initial setting of concrete. Where retarders are used, this waiting period shall be increased to about 6 hours.
- (2) The rate of increase of temperature of ambient air inside the curing chamber shall not exceed 5°C per hour.
- (3) The maximum temperature applied shall be 60°C to 70°C.
- (4) The maximum temperature shall be maintained until concrete has reached the desired strength.
- (5) When Steam Curing is being discontinued, the rate of decrease of temperature of ambient air inside the curing chamber shall not exceed 5°C per hour.
- (6) The temperature of ambient air inside the curing chamber shall be lowered to about 10°C above the temperature of the air to which the concrete will be exposed, and kept steady for  **hours** and discontinued thereafter.

Concrete shall not be exposed to temperatures below 0°C for at least 6 days after curing.

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### C92.1.8 Curing

Curing is the process of preventing the loss of moisture from the concrete, while continuing to maintain a satisfactory temperature regime. Preventing loss of moisture from concrete is important, especially when:

- (1) Water-cement ratio is low,
- (2) Cement has a high rate of strength development, and
- (3) Concrete contains granulated blast furnace slag or pulverised fuel ash.

The curing regime should prevent the development of high temperature gradients within the concrete. The rate of strength development at early ages of concrete made with super-sulphated cement is significantly reduced at lower temperatures. Super-sulphated cement concrete is seriously affected by inadequate curing, and hence the precaution.

Proper curing of concrete will protect it from:

- (1) Premature drying out by solar radiation and wind,
- (2) High internal thermal gradients,
- (3) Leeching out by rain or flowing water,
- (4) Rapid cooling during the first few days after placing of concrete,
- (5) Low temperature or frost, and
- (6) Vibration and impact, which may disrupt the concrete and interfere with its bond to the reinforcement.

Also, it will reduce the permeability of the concrete and enhance its durability by extending the hydration of the cement, particularly in its surface zone.

Where members are of considerable size and length, with high cement content, accelerated curing methods may be applied, as approved by the *Engineer-in-Charge*.

#### C(a) Normal Curing

The rate of strength development at early ages of concrete made with super-sulphated cement is significantly reduced at lower temperatures. Super-sulphated cement concrete is seriously affected by inadequate curing and the surface has to be kept moist for at least seven days.

Curing is crucial during the first 3 days till the Gel formation is not complete. Hence, during the first 3 days of concreting concrete matrix accepts free water from outside into the concrete matrix if there is a shortfall in water-cement ratio due to any unforeseen reasons. Once the gel formation is complete, curing water only reduces the surface temperature of concrete due to exothermic reactions ongoing inside the concrete matrix. This reduction is necessary to control surface cracks due to temperature rise in concrete, and hence is an essential step towards getting healthy concrete.

##### (1) Moist Curing

The curing period of seven days is applicable to concretes made with OPC and Portland Slag Cement. It may be reduced to 3 or 4 days, when Rapid Hardening Portland Cement is used, but greater care should be exercised, particularly at early ages, when the rate of hydration is high. When Low-Heat Portland Cement or Super-Sulphated Cement is used, longer curing period (of say 2 weeks) may be necessary. For High Alumina Cement Concrete, greater care is required in curing. Continuous curing is important, to avoid formation of surface cracking due to alternate wetting and drying.

##### (2) Membrane Curing

Membranes, e.g., polythene sheets or thin films formed by certain liquids (curing compounds), prevent loss of water by evaporation from concrete when applied on to the surface of concrete. Curing compounds consist essentially of waxes, resins, chlorinated rubber and solvents of high volatility. The formulation should be capable of providing a seal

shortly after being applied and should not be used on surfaces that are to receive additional concrete, paint or tile that require a bond, unless the membrane is satisfactorily removed or forms a base that can provide a bond. Hence, the clause requires prior approval by the *Engineer-in-Charge*.

Curing compounds should be applied after the free water on the surface has disappeared and no water sheet is seen, but not so late that the compound is absorbed into the surface pores of the concrete.

On formwork concrete surfaces, the curing compound should be applied immediately after stripping the formwork. In such applications, if the surface is dry, water should be sprayed and it should be allowed to reach a uniformly damp appearance with no free water standing when the compound is applied.

**C(b) Steam Curing**

Steam is required to be 100% relative humidity to prevent loss of moisture and to provide excess moisture for proper hydration of the cement. Also, steam should not be applied directly at any local point on the concrete surface, because such an act may cause local damage to the member at that point.

**92.1.9 Supervising**

It is exceedingly difficult and costly to alter concrete once placed. Hence, constant and strict supervision shall be ensured of:

- (1) All members being concreted during the progress of the construction work, including the proportioning and mixing of the concrete, and
- (2) Reinforcement and its placing before being concreting.

Before any important operation, such as concreting or stripping off the formwork is started, adequate notice shall be given to the construction supervisor.

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**C92.1.9 Supervising**

The manufacture and placing of concrete and reinforcement should be supervised by a person whose qualification and experience are as specified in the *National Building Code 2016*.

**92.1.10 Concreting in Special Conditions**

The provisions given hereunder shall be complied with when concrete under *Hot Weather, Cold Weather, Under Water, Mass Concrete and Aggressive Soil* conditions.

**(a) Hot Weather Concreting**

Concreting in hot weather conditions, *i.e.*, when ambient air temperature is above 40°C or when the temperature of concrete at time of its placement is expected to be beyond 40°C other than during *steam curing*, shall be done as specified in **IS 7861 (Part 1)**. Further, the provisions hereunder shall be applicable to minimize the harmful effects of hot weather on concreting and concrete.

**(1) Temperature Control of Ingredients of Concrete:**

All available means shall be used for maintaining the ingredient materials of concrete at as low temperatures as practicable.

(i) *Aggregates* – Any one of the following procedures or a combination of the same may be used for lowering the temperature or preventing excessive heating of *coarse aggregates*:

- (1) *Shading* stockpiles from direct rays of the sun.
- (2) *Sprinkling with water* the stockpiles of coarse aggregate and keeping them moist. When coarse aggregates are stockpiled, successive layers should be sprinkled as the stockpile is built up. This procedure results in cooling by evaporation, and it is effective especially when relative humidity is low. Such sprinkling should be done uniformly, because it leads to uniformity in surface moisture and thereby gives uniform workability.
- (3) *Heavy spraying of cold water* (if available) on coarse aggregate immediately before use may be done to cool them directly. Alternately, they can be inundated in cold water.
- (4) *Circulating refrigerated air* through pipes in the stock piles of coarse aggregates.

(ii) *Water* – Any one of the following procedures or a combination of the same may be used for lowering the temperature of *water*:

- (1) Use *cold water*; keep it cold by insulating the pipes, water storage tanks, *etc.*
- (2) *Insulate* tanks or trucks used for transporting water, or *colour* them white or yellow.
- (3) Use *mechanical refrigerator* to cool water.
- (4) Use *crushed ice* (in place of water) when mixing concrete.

Under certain circumstances, reduction in water temperature may be most economically accomplished by methods (3) and (4) above. But, on the contrary, in method (4) above, if all ice does not melt completely by the time mixing is completed, and if a portion of ice melts after consolidation of concrete, hollow pockets are left in concrete, which has detrimental effects.

(iii) *Cement* – Any one of the following procedures or a combination of the same may be used for lowering the temperature of *cement*:

- (1) *Storing* cement in shaded areas.
- (2) Ensuring minimal heat gain into the room in which the cement bags are placed, during the day from direct sunlight on its walls and roof.

(2) *Proportioning of Concrete Mix Materials and Concrete Mix Design*

Concrete mix shall be designed with:

- (a) *Minimum cement content* consistent with other functional requirements; and
- (b) *Cements having low heat of hydration*, instead of those having *high fineness* and *high heat of hydration*.

If the temperature is such as to increase *mixing water demand* or reduce *workability*, then *water reducing* and *set-retarding admixtures* may be used to offset the accelerating effects of *high temperatures* and *high mix water*. Any such admixture shall be used only on the recommendation of competent technical advice, or on the basis of advance testing (when practicable) with the cement and other materials involved.

(3) *Temperature of Concrete as placed*

The temperature of concrete at the time of placing shall be maintained below 40°C. Towards this end, the temperature  $T$  (°C) of the freshly mixed concrete at the time of leaving the mixer or batching plant shall be estimated (using the temperature of all its constituents) as:

(a) **Cold water as mix water (without ice)**

$$T = \frac{S(T_a W_a + T_c W_c) + T_w W_w + T_{wa} W_{wa}}{S(W_a + W_c) + W_w + W_{wa}}; \text{ and}$$

(b) **Ice added to the mix water**

$$T = \frac{S(T_a W_a + T_c W_c)}{S(W_a + W_c) + W_w + W_{wa} + W_i} + \frac{(W_w - W_{wa})T_w + W_{wa}T_{wa} - 79.6W_i}{S(W_a + W_c) + W_w + W_{wa} + W_i},$$

where  $T_a$ ,  $T_c$ ,  $T_w$  and  $T_{wa}$  are temperatures (°C) of *aggregate*, *cement*, *mix water* and *free water on aggregate*, respectively,  $W_a$ ,  $W_c$ ,  $W_w$ ,  $W_{wa}$  and  $W_i$  are masses (kg) of *aggregate*, *cement*, *mix water*, *free water on aggregate*, and *ice*, respectively; and  $S$ , the ratio of *specific heat of cement & aggregate* to that of *water*. In practice,  $S$  shall be taken as 0.22 and  $T_{wa} = T_a$ .

The increase in temperature may be taken as 2°C during transportation, in the absence of specific information.

(4) *Production and Delivery*

Temperatures of *aggregate*, *water* and *cement* shall be maintained at the lowest practical levels so that the temperature of the concrete is below 40°C at the time of placement.

*Mixing time* shall be kept to a minimum, to ensure adequate quality and uniformity, because the concrete is warmed from the work of mixing, from the *air* and from the *sun*.

Attention shall be given to *coordinating the delivery* of concrete with the rate of placement to avoid delays in delivery.

(5) *Placement, Protection and Curing*

(a) **Placement and Finishing**

Forms, reinforcement, and sub-grade shall be sprinkled with cool water just prior to placement of concrete. The area around the work shall be kept wet to the extent possible to cool the surrounding air and increase its humidity, thereby reducing temperature rise and evaporation from the concrete. When temperature

conditions are critical, concrete placement may be restricted to the evenings or night when temperature are low and evaporation is less.

Ample personnel shall be employed to handle and place concrete immediately on delivery. On flat work, all steps in finishing shall be carried out promptly.

Concrete shall be placed in layers thin enough and in area small enough so that the time interval between consecutive placements is reduced and vibration or other working of the concrete will ensure complete union of adjacent portions. If cold joints tend to form or if surfaces set and dry too rapidly, or if plastic shrinkage cracks tend to appear, the concrete shall be kept moist by means of fog sprays, wet burlap, cotton mats, or other means.

All placement procedures shall be directed to keep the concrete as cool as practicable and to ensure its setting and hardening, under temperature conditions which are reasonably uniform and, under moisture conditions, which will minimize drying. Concrete, whether delivered by a truck or otherwise, shall reach the forms at a temperature not higher than 40°C, and whatever is practicable shall be done to minimize temperature increase during placing, consolidation, finishing, and curing operations.

**(b) Protection and Curing**

Attention shall be paid to ensure that all surfaces are prevented from drying. Immediately after consolidation and surface finish, concrete shall be protected from evaporation of moisture, without letting ingress or external water, by means of wet (not dripping) gunny bags, Hessian cloth, *etc.* Moist curing shall commence once the concrete has attained some degree of hardening sufficient to withstand surface damage (approximately 12 hours after mixing). The duration of curing shall not be less than 10 days.

Reliance shall not be placed on the protection afforded by forms for curing in hot weather. If possible, water shall be applied to formed surface while forms are still in place and unformed surfaces shall be kept moist by wet curing. The covering material shall be kept soaked by spraying. Steeply sloping and vertical formed surfaces shall be kept completely and continuously moist prior to and during form removal by applying water to top surfaces so that it will pass down between the form and the concrete.

On exposed unformed concrete surfaces, wind breakers shall be provided as far as possible.

On hardened concrete (especially on flat surfaces), curing, water shall not be much cooler than the concrete, because of the possibilities of thermal stresses and resultant cracking. At the termination of curing with water, effort shall be made to reduce the rate of drying by avoiding air circulation.

**(6) Inspection and Temperature Records**

Competent inspection personnel shall be available to anticipate the need for:

- (a) Requirements during hot weather concreting (such as spraying of forms and sub-grade),
- (b) Ice as a portion of the mixing water, providing shades, wind screens, *etc.*, and
- (c) Minimizing delays in placement and curing.

The supervisor shall record at frequent intervals air temperature, general *weather condition* (calm, windy, clear & cloudy), and *relative humidity*. The record shall

include information on frequent checks on temperature of concrete as delivered and after placing in the forms, and the protection and curing time as provided.

All such data shall be gathered with the work in progress such that the conditions surrounding the construction of any part of the structure can be determined (if necessary) at a later date. A copy of all the observations shall be included in the permanent records of the job.

(7) *Concrete Testing*

Extra care shall be exercised to maintain temperature and moisture conditions for strength test specimens as required in standard test methods.

Proper temperature shall be maintained by avoiding exposure to the sun and by utilizing the cooling effect of evaporating water, either from *damp burlap* or *wet sand* covering the specimen.

Specimens used as the basis for acceptance of concrete as delivered to the structure shall be transferred at the age of one day to a location (usually the laboratory) where they will receive continuous standard moist curing until test age of specimen.

Specimens cured on the job shall never be substituted for laboratory cured specimens as a check of the proportioning and mixing of the concrete. Moulded specimens used for these purposes shall be cured at the same place and as nearly as possible under the same conditions as those around the structure.

(b) **Cold Weather Concreting**

Concreting in cold weather conditions, *i.e.*, when ambient air temperature is around 5°C or less, shall be done as specified in **IS 7861 (Part 2)**. Further, the provisions hereunder shall be applicable to minimize the harmful effects of cold weather on concrete and concreting. The degree to which these provisions are applicable depends on circumstances and shall be determined appropriately. For this purpose, cold weather shall be classified into three categories, namely:

- (1) When the temperature is below 5°C, but does not fall below freezing point,
- (2) When frost occurs at night only and is not very severe, and
- (3) When there is severe frost day and night.

**Table 9.6** summarizes the precautions to be taken in each case.

**Table 9.6:** Precautionary measures to be taken during *Cold Weather Concreting*

S.No.	Cold Weather Category	Mitigation Measures
1	When the temperature is below 5°C, but does not fall below freezing point	<ol style="list-style-type: none"> <li>(1) Keep formwork in position for longer duration, or use rapid hardening cement;</li> <li>(2) Cover the top of the concrete with insulating material;</li> <li>(3) Insulate steel formwork; and</li> <li>(4) Make sure that concrete is delivered to the point of placing at not less than 5°C.</li> </ol>
2	When frost occurs at night only and is not very severe	<ol style="list-style-type: none"> <li>(1) Keep formwork in position for longer duration, or use rapid hardening cement;</li> <li>(2) Cover the top of the concrete with insulating material;</li> <li>(3) Insulate all formwork;</li> <li>(4) Make sure that concrete is delivered to the point of placing at not less than 5°C;</li> <li>(5) Make sure that concrete is not placed against a frozen sub-grade or against reinforcement or forms covered with snow or ice; and</li> <li>(6) Place concrete quickly and insulate.</li> </ol>
3	When there is severe frost day and night	<ol style="list-style-type: none"> <li>(1) Keep formwork in position for longer duration, or use rapid hardening cement;</li> <li>(2) Cover the top of the concrete with insulating material;</li> <li>(3) Insulate all formwork;</li> <li>(4) Ensure that concrete is delivered to the point of placing at not less than 5°C;</li> <li>(5) Ensure that concrete is not placed against a frozen sub-grade or against reinforcement or forms covered with snow or ice;</li> <li>(6) Place concrete quickly and insulate;</li> <li>(7) Heat the water, and, the aggregate, if necessary; and</li> <li>(8) Ensure that concrete is delivered to the point of placing at not less than 10°C, place quickly and insulate; or make sure concrete is delivered to the point of placing at not less than 5°C, place quickly and provide continuous heating to the concrete.</li> </ol>

(1) *Temperature Control of Ingredients of Concrete:*

All available means shall be used for maintaining the ingredient materials of concrete at as high temperatures as practicable.

- (i) *Aggregates* – Heating of aggregate shall be such that frozen lumps, ice and snow are eliminated and at the same time over-heating is avoided. At no point shall the aggregate temperature exceed 100°C; the average temperature of aggregate for an individual batch shall not exceed 65°C.
- (ii) *Water* – Mixing water shall be heated under such a control and in sufficient quantity as to avoid appreciable fluctuations in temperature from batch to batch.
- (iii) *Cement* – It is preferable to use *Rapid-Hardening Portland Cement (IS 8041)*.

(2) *Proportioning of Concrete Mix Materials and Concrete Mix Design*

The cement content in the mix shall be not less than 300 kg/m<sup>3</sup>.

Air-entraining admixtures and accelerators, when proposed to, shall conform to the requirements of **IS 9103**, and shall be used only after proper evaluation with the cement and aggregates proposed to be used in the works. If a combination of different admixture is used, preliminary tests shall be carried out with such combination prior to use in the actual construction.

(3) *Calcium Chloride as an Accelerator*

Calcium chloride may be used as an accelerating admixture, except in the following cases:

(a) When concrete is:

- (i) *Cracked,*
- (ii) *Exposed to alternate wetting and drying,*
- (iii) *Protected by small cover is small, and*
- (iv) *Permeable; and*

(b) When galvanized steel is used for permanent forms or for embedded parts;

(c) Prestressed concrete; and

(d) When sulphate resisting concrete is required.

The total calcium chloride in concrete shall be limited to the value specified in **Clause \_\_\_\_\_**.

(4) *Air-Entraining Agents*

The compressive strength at 28 days of air-entrained concrete shall not be less than 90% of a reference mix without air entrainment.

Air-entraining agents shall be permitted in prestressed concrete, only if it does not contain chlorides.

(5) *Temperature of Concrete as placed*

The temperature of concrete at the time of placing shall be maintained above 5°C. Towards this end, the temperature  $T$  (°C) of the freshly mixed concrete at the time of leaving the mixer or batching plant shall be estimated (using the temperature of all its constituents) as:

$$T = \frac{S(T_a W_a + T_c W_c) + T_w W_w + T_{wa} W_{wa}}{S(W_a + W_c) + W_w + W_{wa}},$$

where  $T_a$ ,  $T_c$ ,  $T_w$  and  $T_{wa}$  are temperatures (°C) of aggregate, cement, mix water and free water on aggregate, respectively,  $W_a$ ,  $W_c$ ,  $W_w$  and  $W_{wa}$  are masses (kg) of

aggregate, cement, mix water, free water on aggregate, and ice, respectively; and  $S$ , the ratio of specific heat of cement & aggregate to that of water. In practice,  $S$  shall be taken as 0.22 and  $T_{wa} = T_a$ .

The drop in temperature may be taken as 2°C during transportation, in the absence of specific information.

(6) *Production and Delivery*

Preparation for concreting in cold weather shall be completed well in advance of setting in of severe conditions. Wind breakers shall be erected to shield the mixing and batching plants. Also, steam generating plant or other necessary equipment shall be installed and checked for correct functioning. Further, suitable protecting clothing shall be available to the site staff. The operators shall be instructed on the procedure for concreting during cold weather.

The concrete shall be delivered to the point of placing at not less than 5°C. It is necessary to place the concrete quickly and cover the top or the concrete with an insulating material.

(7) *Placement*

**(a) Placement and Finishing**

Before any concrete is placed, all ice, snow and frost shall be removed completely and the temperature of all surfaces to be in contact with new concrete shall be raised as close to the temperature of fresh concrete to be placed thereon as practicable. No concrete shall be placed on a frozen sub-grade or on one that contains frozen materials.

Arrangements for covering and insulating of newly placed concrete shall be made in advance of placement and shall be adequate to maintain in all parts of concrete, the temperature and moisture conditions that are referred to herein for winter curing temperature and methods.

**(b) Protection**

During cold weather, all concrete surfaces shall be covered as soon as the concrete has been placed to keep the heat in and to help prevent freezing.

**(c) Curing**

For concrete cast in insulated formwork, the member shall be covered completely to retain sufficient water for the hydration of the cement. On removal of the formwork and insulation, the member shall be immediately covered with plastic sheet or tarpaulins, properly lapped and made wind-tight. On no account shall such concrete, just released from insulated formwork, be saturated with cold water. When protective measures are to be discontinued, the surface temperature or the concrete shall be adjusted gradually to the air temperature.

**(d) Removal of Forms**

The time limit indicated for removal of formwork to the sides of beams, columns and wall shall, in no case, be less than the pre-hardening period (**Table 9.7**).

**Table 9.7:** Minimum Pre-hardening Periods

Grade of Concrete	Requisite Pre-Hardening Period (hours) at stated curing temperature of concrete in house			
	20°C	15°C	10°C	5°C
M 20	24	32	46	71
M 25	22	30	42	65
M 30	20	27	38	59
M 40	17	23	33	50

(8) *Inspection, Temperature and Humidity Records*

During cold weather inspection, personnel shall keep a record of the date, time, outside air temperature, temperature of concrete at the time of placing and general weather (calm, windy, clear, cloudy, etc.). The record shall include the temperature at several points within the enclosure and on the concrete surface, corners and edges in sufficient number to show the *highest* and the *lowest* temperatures of the concrete.

When using an accelerator in approved dosage, the minimum pre-hardening period can be reduced by 25%. But, whatever the measure taken to accelerate the hardening, the minimum pre-hardening period shall not be less than the values in **Table 9.8**.

**Table 9.8:** Minimum Pre-hardening Periods

Curing Temperature (°C)	12	16	24	36
Minimum pre-hardening Period (hours)	20	15	10	5

(9) *Concrete Testing*

The testing of the properties of the concrete constituents shall be carried out in accordance with **IS 1199**. Test results shall be used for fixing the time of removal of insulations, forms, etc., or be the basis for further precautions at the building site. In addition to the regular quality control, the following shall be considered:

- (a) Determine suitability of concrete making materials for winter concreting and control of the properties of fresh concrete;
- (b) Record air and concrete temperatures at placing and during concreting; and
- (c) Control strength development in the structure by testing similarly cured specimens.
- (d) The specimens shall not be tested in *frozen state*.

**(c) Under-Water Concreting**

When it is necessary to deposit concrete under water, the methods, equipment, materials and proportions of the mix to be used shall be submitted to and approved by the *Engineer-in-Charge* before the work is started.

- (1) Under-water concrete should have a slump specified in **Clause 61.4.7**. The water-cement ratio shall not exceed 0.6 and may need to be smaller, depending on the grade of concrete or the type of chemical attack. For aggregates of 10 mm, 20 mm and 40 mm nominal maximum sizes, the cement content shall be at least 420 kg/m<sup>3</sup>, 380 kg/m<sup>3</sup> and 350 kg/m<sup>3</sup> of concrete, respectively.
- (2) Cofferdams or forms shall be sufficiently tight to ensure still water, if practicable, and in any case to reduce the flow of water to less than 3m/min through the space into which concrete is to be deposited. Cofferdams or forms in still water shall be sufficiently tight to prevent loss of mortar through the walls. De-watering by pumping shall not be done, while concrete is being placed or until 24 hours thereafter.
- (3) Concrete shall be deposited, continuously until it is brought to the required height. While depositing, the top surface shall be kept as nearly level as possible and the formation of seams avoided.

The methods to be used for depositing concrete under water shall be one of the following:

- (i) Tremie Concreting,
- (ii) Direct placement with pumps,
- (iii) Drop bottom bucket,
- (iv) Bags, and
- (v) Grouting.

To minimize the formulation of laitance, great care shall be exercised not to disturb the concrete as far as possible while it is being deposited.

Ingredient materials of concrete to be placed under water shall meet all relevant specifications. In addition, the following shall apply:

- (1) The maximum size of aggregate shall be 20mm for reinforced concrete members, but can be 40mm for non-reinforced concrete members.
- (2) The *high-range water reducing admixtures* for placement of mass concrete (like Polycarboxylate or base superplasticizers) shall not be used, unless slump loss testing has shown no detrimental results. They may be used for placement of small masses of concrete.
- (3) Cementitious materials shall not be less than 360kg/m<sup>3</sup>, and the maximum ratio of water in cementitious materials shall be restricted to 0.45. Fine aggregate shall be 40%-55% of total aggregate. The slump shall be maintained in the range of 150mm-230mm.

**(d) Mass Concreting**

The general construction practices to be followed during mass concreting of plain and reinforced structures shall be as per **IS 457**.

**(e) Concreting in Aggressive Soils**

Requirements for concrete exposed to sulphate attack are provided in **Clause 8.2.2.4**. At sites where alkali concentrations are high or may become very high, the ground water shall be lowered by drainage so that it will not come into direct contact with the concrete. Additional protection shall be obtained by the use of impermeable barriers.

In addition to the grade of concrete specified, the minimum cement content and maximum water-cement ratio shall be controlled. Also, Portland Slag Cement shall be used in consultation with subject specialists.

**C93.1.10 Concreting in Special Conditions**

Five special conditions of concreting are considered in this standard.

**C(a) Hot Weather Concreting**

Concreting operations done at atmospheric temperatures above 40°C need special attention. **IS 7861 (Part 1)** gives the recommended practices that would result in concrete possessing improved characteristics in the fresh as well as hardened state.

Effects of hot weather on *concrete* are:

- (1) *Accelerated Setting*: High temperature increases the rate of setting of concrete. The duration of time during which the concrete can be handled is reduced. Quick stiffening may necessitate undesirable re-tempering by addition of water. Also, it may result in cold joints.
- (2) *Reduction in Strength*: High temperature results in the increase the quantity of mixing water to maintain the workability with consequent reduction in strength.
- (3) *Increased Tendency to Crack*: Either before or after hardening plastic shrinkage cracks may form in the partially hardened concrete due to rapid evaporation of water. Cracks may be developed in hardened concrete either by increased drying shrinkage resulting from greater mixing water used, or by cooling of the concrete from its elevated initial temperature.
- (4) *Rapid Evaporation of Water during Curing*: It is difficult to retain moisture for hydration and maintain reasonably uniform temperature conditions during the curing period.
- (5) *Difficulty in control of Air Content in Air-Entrained Concrete*: It is more difficult to control air content in air-entrained concrete. This adds to the difficulty of controlling workability. For a given amount of air-entraining agent, hot concrete will entrain less air than concrete at normal temperatures.

Effects of hot weather on *properties of concrete* are:

- (1) *Compressive Strength*: The desirable properties of concrete, *e.g.*, strength, impermeability, dimensional stability, and resistance to weathering, wear & chemical attack, can be adversely affected by combinations of high air temperature, low relative humidity and high wind velocity. Concretes mixed, placed and cured at elevated temperatures normally develop higher early strength than concretes produced and cured at normal temperatures, but at 28 days or later, the strengths are lower (**Figure C9.2**). Further, reduction in strength can occur if sufficient water curing is absent, or if there is considerable delay in the commencement or moist curing. Tests have shown that *laboratory test* specimens moulded and cured at 23°C with 60% relative humidity and at 38°C with 25 % relative humidity produced strength of only 73% and 62%, respectively, of that obtained for standard specimens moist cured at 23°C for 28 days.
- (2) *Workability and Water Demand*: For maintaining the same workability, the quantity of water in the concrete mix should be increased with increase in concrete temperature. Alternatively, if the amount of water remains unchanged as the temperature of concrete increases, then workability will increase (**Figure C9.3**). An increase of 11°C in temperature is expected to decrease the slump by 25 mm. Also, amount of water should be changed to produce the same slump of 25 mm at various temperatures; as the temperature increases from 5°C to 27°C, about 2.25%–2.5% additional water will be required to effect a 25 mm change in slump, and as the temperature reaches 49°C, about 4.5% additional water will be required. The actual water content in a mix to meet a given workability will depend on *actual mix proportions, workability desired and temperature*. **Figure C9.4** illustrates the water required to get a 75 mm slump, in concrete (with maximum size of aggregate 40 mm) at different temperatures.

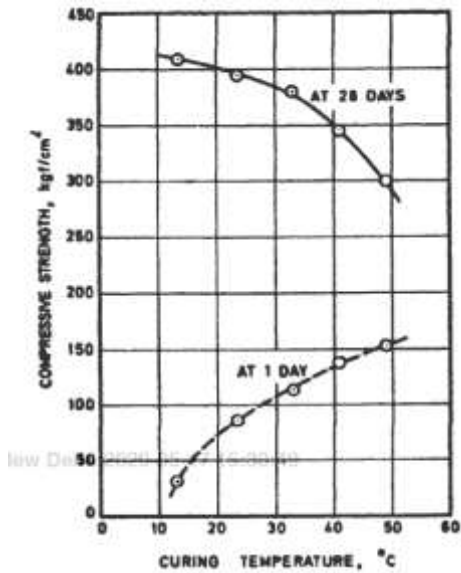


Figure C9.2: Effect of curing temperature on 1-day & 28-day compressive strengths of concrete

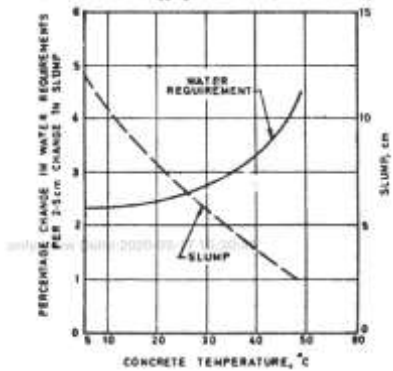


Figure C9.3: Effects of concrete temperature on slump, and water required to change slump

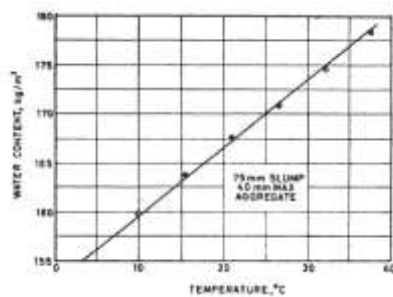
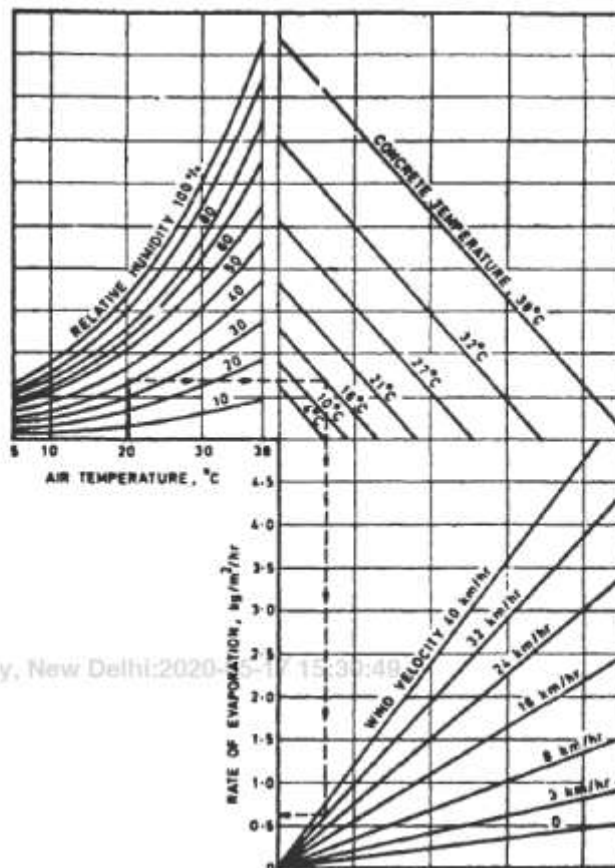


Figure C9.4: Effects of Temperature on water required in concrete for maintaining 75mm slump

(3) *Shrinkage*: In the hot weather, *plastic shrinkage* cracking will occur (in *green* concrete) when the rate of evaporation of water from the concrete mix is higher than that at which water rises to the surface of freshly placed concrete (bleeding). High *concrete temperature*, high *air temperature*, high *wind velocity* and low *relative humidity*, or combinations thereof cause rapid evaporation of water, which significantly increases the likelihood of *plastic shrinkage cracking*. A graphic method of estimating the loss of surface moisture for various concrete and air temperatures, relative humidity and wind velocity is given in **Figure C9.5**. The four steps to estimate the evaporation rate are:

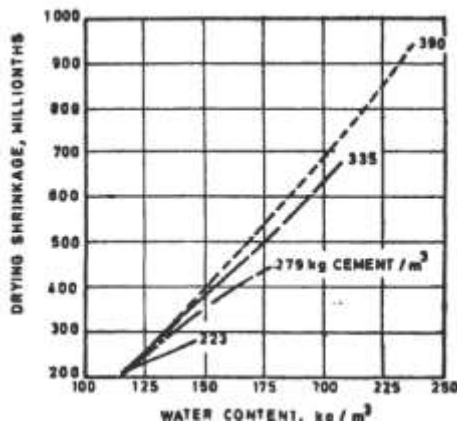
- With a known air temperature, move up to relative humidity.
- Move right to concrete temperature,
- Move down to wind velocity, and
- Move left to read approximate rate of evaporation.

When the rate of evaporation approaches  $1.0\text{kg}/\text{m}^2/\text{h}$ , precautions should be taken to mitigate *plastic shrinkage cracking*.



**Figure C9.5:** Effects of Concrete and Air Temperatures, Relative Humidity, and Wind Velocity on Rate of Evaporation of surface moisture from concrete

Drying shrinkage (in *hardened* concrete) increases with the increase in water content in the mix and lowering of relative humidity. Increase in the concreting temperature increases water demand which may lead to increased drying shrinkage. **Figure C9.6** shows the relationship between drying shrinkage and unit water Content, for various amounts of cement in the mix. It shows that shrinkage is a direct function of the unit water content of the fresh concrete and cement content (or water-cement ratio) has only a secondary importance. Subsequent cooling from high temperatures, at which the concrete hardens, increases the cracking tendency of concrete.



**Figure C9.6:** Relation between Shrinkage, Cement Content and Water Content

Good practices of concreting under hot weather conditions require special care with respect to the following:

(1) *Temperature control of concrete ingredients:*

- (i) Aggregates stored under shade or cooled by water,
- (ii) Water used in the form of ice or in near freezing temperatures, and
- (ii) Cement temperature restricted to 77°C.

(2) *Mix Design:*

- (i) Use low cement content and cements with low heats of hydration, and
- (ii) Use approved admixtures for reducing the water demand or for retarding the set.

(3) *Production and Delivery:*

- (i) Temperature of concrete at the time of placement below 40°C,
- (ii) Mixing time held at minimum, subject to uniform mixing, and
- (iii) Period between mixing and delivery kept to a minimum.

(4) *Placement and Curing:*

- (i) Prior to placing concrete formwork, reinforcements and sub grade kept cool by spraying with cold water first, and if possible, concreting restricted to evenings or nights, and
- (ii) Speedy placement and finishing.
- (iii) Concrete protected from moisture immediately after compacting and finishing.

The mitigation measures to overcome negative effects of hot weather concreting are:

(1) *Temperature Control of Concrete Ingredients*

- (a) A direct approach to keep concrete temperature down is to control the temperature of its ingredients. The contribution of each ingredient to the temperature of concrete is a function of the temperature, specific heat, and quantity used of that ingredient. The aggregates and mixing water exert the most pronounced effect on temperature of concrete. Hence, the provision permits all available means to maintain these materials at as low temperatures as practicable.
- (i) *Aggregates* – The provision recognizes four common methods of lowering temperature of aggregates. Other suitable methods should be explored by construction agencies.
- (ii) *Water* – The water used in mixing concrete has high effect on temperature of concrete, since it has a specific heat of about 4.5 to 5 times that of cement or aggregate. The temperature of water is easier to control than that of other ingredients and, even though water is used in smaller quantities than the other ingredients, the use of cold mixing water will effect a moderate reduction in concrete placing temperatures. For a nominal concrete mixture of 1m<sup>3</sup> containing 336kg of cement, 170kg water and 1,850kg of aggregate, a change in 2°C water temperature will effect a 0.5°C change in the concrete temperature (Figure C9.7). The temperatures mentioned here are normal mixing water temperatures; these are applicable to average mixes made with typical natural aggregates. Quantity of cooled water cannot exceed mixing water requirement, which will depend on moisture content of aggregate and mix proportions. Alternately, ice can be used (Figure C9.8).
- (iii) *Cement* – Temperature of concrete has a direct effect on the rate of hydration of cement. High concrete temperature increases rates of hydration and stiffening, and generally results in increased water demand, thus reducing strength and increasing plastic shrinkage. Temperature has a definite effect on setting time; the magnitude of the effect varies with the cement composition when a set-controlling admixture is used. The change in temperature of cement produces significantly less change in the temperature of fresh concrete than the other ingredients. But, it does exert an effect, and it is prudent to place an upper limit on temperature of cement, as it enters the concrete. Cement shall not be used preferably at temperatures in excess of about 77°C.

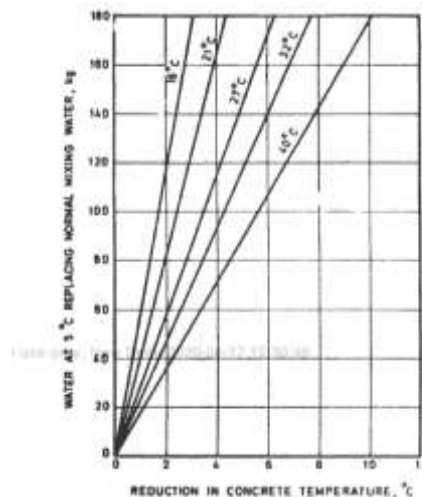
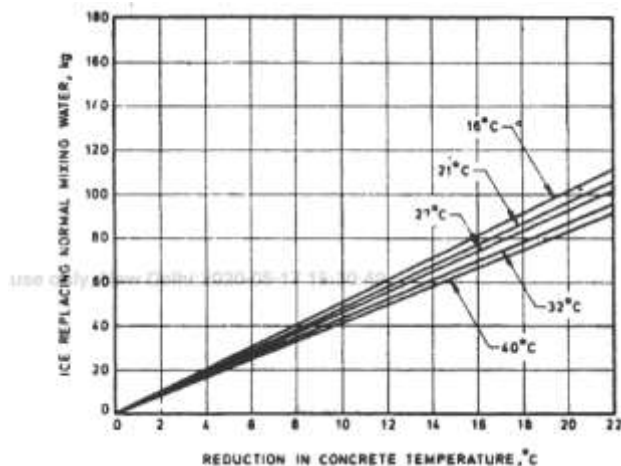


Figure C9.7: Effect of using cold water in mixing of concrete on temperature of concrete



**Figure C9.8:** Effect of using ice in mixing of concrete on temperature of concrete

Consider a concrete mix having the following ingredients of concrete (per m<sup>3</sup>), and the initial temperature shown against each:

Material	Mass (kg)	Temperature (°C)
Cement	300	5
Water	210	60
Aggregates	1,779	1

It is assumed that the total aggregate contains coarse and fine fraction in the ratio 2:1, and moisture content in the aggregates (taken to be damp) is 4% in fine aggregates and 1% in coarse aggregates. Therefore,  $W_{ws} = 35.38$  kg, and  $T_{ws} = 1^\circ\text{C}$ .

The temperature (°C) of fresh concrete as mixed with these ingredients will be:

$$T = \frac{0.22(1779 \times 1 + 300 \times 5) + 210 \times 60 + 35.58 \times 1}{0.22(1779 + 300) + 210 + 35.58} = 19^\circ\text{C}$$

(2) *Proportioning of Concrete Mix Materials and Concrete Mix Design*

The quantity of cement used in the mix affects the rate of increase in temperature. In hot weather, hydration of cement is accelerated by high temperature and this acceleration is generally considered responsible for the increase in water requirement of concrete.

(3) *Temperature of Concrete as placed*

Where necessary, the ingredients of concrete should be cooled to the extent necessary. Apart from assessing the temperature of concrete mix as per this clause, the temperature of concrete should be ascertained also from a sample of the design mix. For this purpose, a suitable metal-clad thermometer may be used by embedding it in concrete.

(4) *Production and Delivery*

The effect of mixer surface exposed to the hot sun should be minimized by painting and keeping the mixer drum yellow or white and spraying it with cool water.

Cement hydration, temperature, loss of workability, and loss of entrained air, increase with passage of time after mixing. Thus the period between mixing and delivery shall be kept to an absolute minimum.

(5) *Placement, Protection and Curing***(a) Placement and Finishing**

Speed of placement and finishing helps to minimize problems in hot weather concreting. Delays contribute to loss of workability and lead to use of additional mixing water to offset such loss. Delays in finishing air-entrained concrete pavement in hot weather may lead to formation of a rubbery surface which is impossible to finish without leaving riding that impair the riding qualities of pavement.

Fog sprays applied shortly after placement and before finishing, have been found to be particularly effective in preventing plastic shrink cracks when other means have failed.

**(b) Protection and Curing**

Since hot weather leads to rapid drying of concrete, protection and curing are far more critical than during cold weather. Continuous curing is important, because volume changes due to alternate wetting and drying promote the development of surface cracking. The actual duration of curing depends upon *mix proportions, sizes of members and environmental conditions*; but, in any case, it shall not be less than 10 days.

On exposed unformed concrete surfaces, such as pavement slabs, wind is an important factor in the drying rate of concrete. For example, other conditions being equal, a gentle wind of 15 km/h will cause four or more times as much evaporation from a flat surface as still air. Hence, the clause requires use of wind breakers.

To reduce the rate of drying through air circulation, the removal of wet covers should be delayed until they are dry.

(6) *Inspection and Temperature Records*

The clause emphasizes the importance of maintaining the records during construction.

(7) *Concrete Testing*

Due to the small size of the test specimen in relation to most structural components, test specimens are likely to reach high temperatures and dry more rapidly than the concrete in place, with correspondingly increased detrimental effects. For those reasons, the clause seeks extra care to be taken.

The results of tests of job-cured specimens properly interpreted may be used to obtain information helpful in judging when to strip forms, put the structure in service, etc.

Sometimes, it is desirable to conduct tests, such as workability, air content and moisture content of materials if sprinkled with water, more frequently than for normal conditions. Additional tests, such as temperature of materials and the fresh concrete, initial and final setting time, and temperature and relative humidity at the forms may also be conducted.

**C(b) Cold Weather Concreting**

Effects of cold weather on *concrete* are:

- (1) *Delayed Setting*: Low temperature retards the rate of setting of concrete. The duration of time during which the concrete can be handled is increased compared to concretes at normal temperatures. The hardening period necessary before the removal of forms is thus increased and the experience from concreting at normal temperature cannot be used directly.
- (2) *Freezing of Concrete at Early Ages*: When concrete is exposed to freezing temperature, there is the risk of concrete suffering irreparable loss of strength and other qualities, *i.e.*, permeability may increase and the durability may be impaired.

- (3) *Repeated Freezing and Thawing of Concrete*: If concrete is exposed to repeated freezing and thawing after final set and during the hardening period, the final qualities of the concrete also may be impaired.
- (4) *Stresses Due to Temperature Differentials*: It is a general experience that large temperature differentials within the concrete member may promote cracking and have a harmful effect on the durability. Such differentials are likely to occur in cold weather at the time of removal of form insulations.

Effects of cold weather on *properties of concrete* are:

- (1) *Compressive Strength*: Concretes mixed, placed and cured at temperatures lower than the normal develop strength at a slower rate. Effects of temperature of concrete on the development of compressive strength during the first 28 days can be expressed as in **Figure C9.9** from which it can be seen that the Strength could be lowered by 40-60%, even at temperature 5-10°C. But, this slower development of initial strength does not necessarily impair the long term strength and adequately protected concrete in winter would have the long term strength not significantly lower than at normal temperatures.
- (2) *Freezing of Fresh Concrete*: Freshly placed concrete is vulnerable to freezing temperatures, so much so that if water in fresh concrete is allowed to be frozen, irreparable damage to the quality of concrete and permanent lowering of compressive strength can occur. Water, upon freezing, increases in volume by 9%, which in ordinary concrete may mean an expansion of up to 2%. If concrete, while still plastic is allowed to freeze, the expansion of water could render the concrete useless and such damage would be obvious once the formwork is removed. Concrete, which has stiffened, but not attained sufficient maturity to withstand such disruptive forces, can be damaged upon freezing in that the bond between the aggregate and the cement paste is weakened. This results in lowering of the compressive strength by 30%-50% even for one cycle of freezing; the extent of damage depending upon the maturity attained (**Figure C9.10**).

To safeguard against such damage by early freezing, fresh concrete is required to be protected and its temperature maintained above freezing till such time that it attains sufficient strength to withstand the disruptive forces. The length of such pre-hardening time is specified either in term or the period it attains certain compressive strength varying from 2MPa-7MPa or in terms of days the actual period depending upon the cement content, water-cement ratio and the degree of saturation. The minimum pre-hardening periods specified in **Table C???** refer to the time required for the concrete to attain a minimum compressive strength of 2 MPa and is longer, the lower the grade of concrete.

- (3) *Freezing and Thawing Cycles on Hardened Concrete*: Similar disruptive effects of freezing of pore water make hardened concrete vulnerable to repeated cycle of freezing and thawing, even beyond the minimum pre-hardening period. Usually, damages due to freezing and thawing are measured in terms of lowering of dynamic modulus of elasticity of concrete. Using the data on loss of dynamic modulus of elasticity with the number of freezing and thawing cycles on the one hand and the relationship between compressive strength and dynamic modulus of plasticity on the other, a typical relation between the loss of compressive strength or the dynamic modulus of elasticity of concrete and the number of freezing and thawing, cycle is given **Figure C9.11**. Entrapment of discrete air bubbles in the pore system of the concrete, by means of air entraining admixture, is the best remedy. Such voids do not contain water from the capillary pores due to surface tension effects, but under freezing conditions they behave as expansion chambers to accommodate the ice formed. Properly air-entrained concrete is satisfactory even in severe winter condition provided other precautions in mixing, placing and curing have been taken.

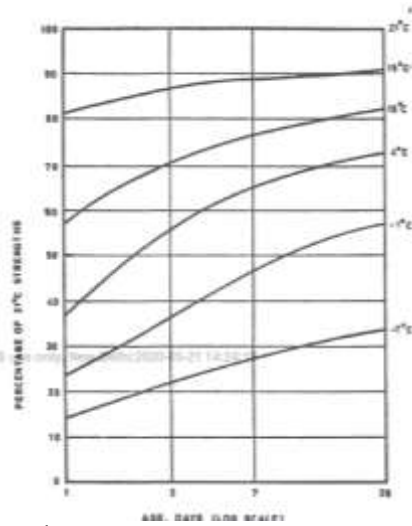


Figure C9.9: Effect of Low Temperature on Compressive Strength of Concrete

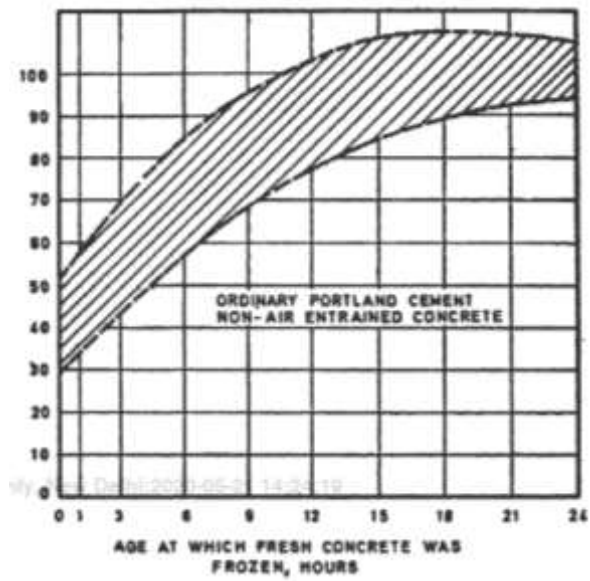
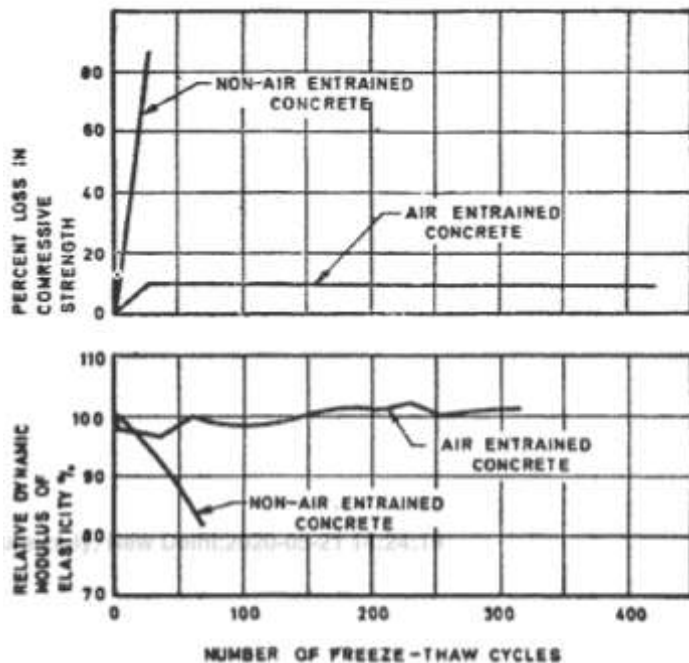


Figure C9.10: Effect of Early Freezing of Concrete



**Figure C9.11:** Effect of Repeated Freezing and Thawing on Hardened Concrete

(1) *Temperature Control of Ingredients of Concrete:*

A direct approach to keep concrete temperature up is to control the temperature of its ingredients. The contribution of each ingredient to the temperature of concrete is a function of the temperature, specific heat, and quantity used of that ingredient. The *aggregates* and *mixing water* exert the most pronounced effect on temperature of concrete. Hence, the provision permits all available means to maintain these materials at as low temperatures as practicable.

(i) *Aggregates* - The heating of aggregates to temperatures higher than 15°C is rarely necessary with mixing water at 60°C.

Any one of the following procedures or a combination of the same may be used for increasing the temperature or preventing excessive cooling of *coarse aggregates*:

- (1) If the coarse aggregate is dry and free of frost and ice lumps, adequate temperatures of fresh concrete can be obtained by increasing the temperature of only the sand, which will seldom have to be higher than about 40°C, if mixing water is at 60°C.
- (2) Steam in embedded pipes is recommended for heating aggregate, but for small jobs aggregates may be heated with the help of steel drums embedded in heaped aggregates and filled with fire. When aggregates in stockpiles are heated by steam pipes, exposed surfaces of aggregate shall be covered with tarpaulins as much as practicable to maintain uniform distribution of heat and to prevent formation of frozen crusts.

- (ii) *Water* - The required temperature of mixing water to produce specified concrete is shown in **Figure C9.12**; these graphs are obtained using: (a) aggregates with moisture content of 4% in *fine aggregates* and 1% in *coarse aggregates* when damp, and of 8% in *fine aggregates* and 2% in *coarse aggregates* when *wet*; (b) Temperature of aggregate and contained moisture of 1°C; and (c) Temperature of cement of 5°C.

To avoid possibility of flash set when either aggregate or water is heated to a temperature in excess of 40°C, water and aggregate shall be mixed together in the mixer first in such a way that the high temperature of one or other is reduced before cement is added. The heated water shall come into direct contact with aggregate first and not cement.

Any one of the following procedures or a combination of the same may be used for increasing the temperature of *water*:

- (1) Water having temperature up to the boiling point may be used provided the aggregate is cold enough to reduce the temperature of the mixing water and aggregate to appreciably below 40°C. Normally, this temperature shall not exceed 25°C.
  - (2) If loss of effectiveness of air entraining admixtures is noticed due to hot water, the admixture may be added to the batch only after water temperature has been reduced.
- (iii) *Cement* - Use of correct type of cement is critical in cold weather concreting.

Consider a concrete mix having the following ingredients of concrete (per m<sup>2</sup>), and the initial temperature shown against each:

Material	Mass (kg)	Temperature (°C)
Cement	336	35
Water	170	30
Coarse Aggregates	1,850	45

It is assumed that the aggregates are dry, *i.e.*,  $W_{wa} = 0$ .

**(a) Cold Water as Mix Water (Without Ice)**

The temperature (°C) of fresh concrete as mixed with these ingredients will be:

$$T = \frac{0.22(45 \times 1850 + 35 \times 336) + 30 \times 170}{0.22(1850 + 336) + 170} = 39.9 \text{ } ^\circ\text{C}$$

If the mix water added is at 5 °C, then the temperature of concrete as mixed will be:

$$T = \frac{0.22(45 \times 1850 + 35 \times 336) + 5 \times 170}{0.22(1850 + 336) + 170} = 33.4 \text{ } ^\circ\text{C}$$

Hence, reduction in concrete temperature is  $39.9^\circ\text{C} - 33.4^\circ\text{C} = 6.5^\circ\text{C}$

**(a) Cold Water as Mixing Water (With Ice)**

If 50% of the mix water (*i.e.*, 85 kg) is replaced by ice, then the temperature of fresh concrete as mixed will be:

$$T = \frac{0.22(45 \times 1850 + 35 \times 336) + (170 - 85) \times 30 - 79.6 \times 85}{0.22(1850 + 336) + 85 + 85} = 25.6 \text{ } ^\circ\text{C}$$

Hence, reduction in concrete temperature is  $39.9^\circ\text{C} - 25.6^\circ\text{C} = 14.3^\circ\text{C}$

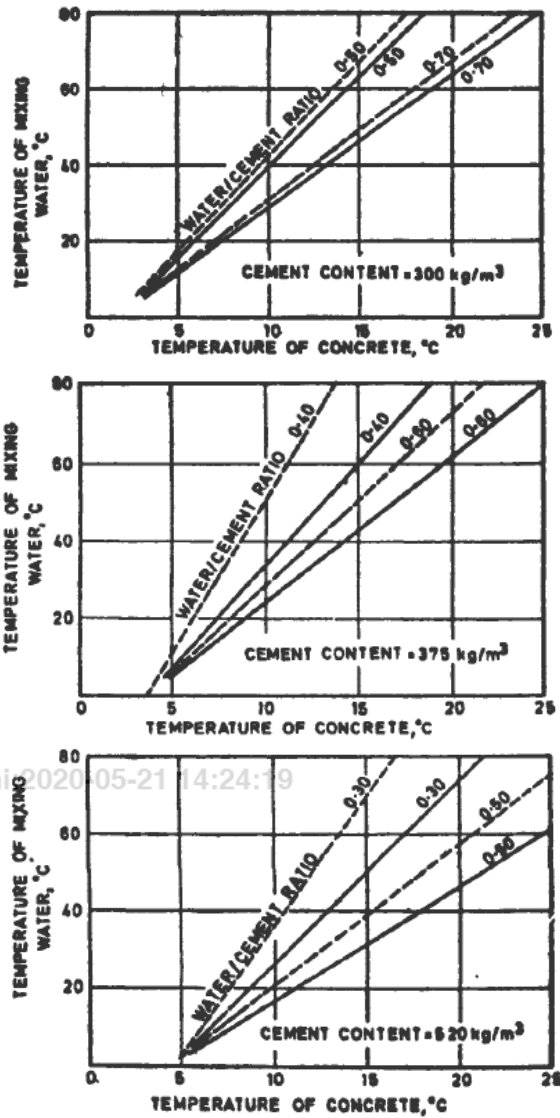


Figure C9.12: Required temperature of mixing water to produce heated concrete

(2) *Proportioning of Concrete Mix Materials and Concrete Mix Design*

In general, for the winter conditions prevailing in India, satisfactory concreting can be achieved mainly by conserving the heat of hydration of cement with insulations and insulated formworks. Wherever damage to hardened concrete by alternate freezing and thawing during service is anticipated, air entrainment is necessary. The type and quantity of cement used in the concrete mix affect, the rate of development of compressive strength and rate of increase in temperature of concrete. Additional quantity of *Ordinary Portland Cement*, *Rapid-Hardening Portland Cement* or use of *accelerating admixtures*, when used with proper precautions, helps in development of the required strength in a shorter period. This often results in saving due to shorter duration of protection, faster re-use of form earlier removal of shores and less labour in finishing the work. Use of cement which gives earlier and higher rate of hydration is preferable.

(3) *Calcium Chloride as an Accelerator*

When chlorides are used as admixtures in the said conditions, corrosion is higher. Hence, calcium chloride is not recommended for use as accelerating admixture in such construction.

- (b) The presence of chlorides has been associated with corrosion of galvanized steel, when this material is used for permanent forms or for embedded parts.
- (c) Recent studies have indicated that galvanic corrosion or metal is intensified by addition of calcium chloride to concrete.
- (d) Calcium chloride increases the risk of alkali aggregate reaction, unless controlled by the use of low alkali cement or by addition of pozzolana.
- (e) The use of calcium chloride in prestressed concrete because of its potential danger in augmenting stress corrosion.
- (f) Where sulphate resisting concrete is required, calcium chloride reacts with it and hence not recommended.

Also:

- (1) Tests have indicated that increase in strength resulting from the use of calcium chloride usually can be maximum in 1 to 3 days; the relative increase in flexural strength in concrete is not as high as increase in compressive strength, and decrease in flexural strength may occur at 28 day or later ages.
- (2) There are insufficient data on the use of calcium chloride with Portland slag cement or other blended cements to justify any recommendations concerning the use of chlorides with such cements.
- (3) As calcium chloride precipitates most air-entraining agents and some water retaining agents when mixed in the same solution, it is important that these be kept in separate solutions and introduced separately into the mixer.
- (4) When calcium chloride is used, the doses should be dissolved in a portion of mixing water before batching, since undissolved lumps may, later on, disfigure concrete surfaces.
- (5) While making solution of calcium chloride, add calcium chloride to water and not water to calcium chloride, as it is an exothermic reaction and may cause accident.
- (6) Calcium chloride, or other chemicals in the mix, if used in permissible amounts, will not lower the freezing point of concrete to any significant degree.
- (7) The use of harmful materials to protect the concrete from freezing are not be permitted.

(4) *Air-Entraining Agents*

Air-entraining admixtures in proper amounts increase the resistance of hardened concrete to freezing and thawing, and normally at the same time improve the workability of fresh concrete. A small increase in shrinkage may occur.

(5) *Temperature of Concrete as placed*

In cold weather, the temperature of concrete at the time of placement goes below the optimum placement temperature. When placing concrete at or near freezing temperature, precautions need to be taken to ensure that concrete at the time of placing has a temperature of at least 5°C, and that the temperature of concrete (after having been placed and compacted) is maintained above 2°C until it has *hardened thoroughly*.

Also, the ingredients of concrete should be heated to the extent necessary to maintain the temperature of concrete at the time of placing not less than 5°C.

Apart from assessing the temperature of concrete mix, the temperature of concrete shall be ascertained from sample of the design mix. For this purpose, a suitable metal-clad thermometer may be used by embedding it in concrete.

(6) *Production and Delivery*

The...

(7) *Placement*

Tarpaulin, plastic sheet and other covering and insulating materials may be made available on the site.

(a) **Placement and Finishing**

Where concrete is to be placed over permanently frozen ground, sub-grade material may be thawed deep enough to ensure that it will not freeze back up to the concrete or it may be covered with a sufficient depth of dry granular material.

(b) **Protection**

Clean straw blankets, about 50 mm thick, sacking, tarpaulins, expanded polystyrene, plastic sheet in, and waterproof paper can all be used in conjunction with air gap as an insulation. If possible, insulating material shall be placed against any formwork before concreting and the same can be used as protection after the formwork has been stripped.

Recommendations for protection are given in **Table C9.1** for concrete walls and floor slabs above ground, and in **Table C9.2** for concrete slabs be laid on ground at a temperature of 4.4°C, the concrete being placed at 10°C in each instance. The requirements are calculated for blanket type insulation with a conductivity of 360.6W/m°C/m<sup>2</sup> for a thermal gradient of 0.22°C per cm and the values given are for still air conditions. The equivalent thicknesses of various insulating materials that may be used are given in **Table C9.3**. For cement content values between those given in **Table C9.1** and **Table C9.2**, allowable air temperatures may be linearly interpolated near or below freezing.

Enclosure may be heated by steam, steam pipes, and other type of heaters. Enclosures may be made of wood, canvas, fiber insulation board, plywood, *etc.* During placement or unformed concrete, tarpaulins or other readily movable covering supported on framework shall follow closely the placing of concrete, so that only a small area or finished slab is exposed to outside air at any time. Such tarpaulins shall be used so that hot air can be circulated freely on the slab. Layers of insulating materials placed directly on the concrete are also effective in protecting the concrete.

(c) **Curing**

During periods of freezing or near-freezing conditions, water curing is not necessary, as loss of moisture from the concrete by evaporation is greatly reduced in cold air conditions.

Low pressure wet steam provides the best means of both heating the enclosures and moist curing the concrete. Early curing with liquid membrane-forming compounds may be followed on concrete surface with heated enclosures. It is better to cure first with exhaust steam during the initial period of protection and then apply a curing compound after the protection is removed and the air temperature is above freezing.

**Table C9.1:** Insulation for Walls and Slabs above Ground

Wall Thickness (mm)	Minimum Air Temperature (°C) Allowable for Thickness of Blanket Insulation			
	12 mm	25 mm	37 mm	50 mm
<b>Minimum Cement Content = 300 kg/m<sup>3</sup></b>				
150	7.2	1.7	-5.6	-10
300	1.7	-9.4	-21	-32
450	-2.8	-19	-36	-54
600	-5.0	-23	-46	-
900	-7.8	-29	-	-
1200	-8.3	-31	-	-
1500	-8.9	-32	-	-
<b>Cement Content = 400 kg/m<sup>3</sup></b>				
150	6.7	0	-8.9	-14
300	0	-13	-27	-41
450	-6.1	-26	-46	-67
600	-7.8	-30	-	-
900	-11	-34	-	-
1200	-12	-38	-	-
1500	-12	-40	-	-

**Table C9.2:** Insulation for Slabs on Ground

Wall Thickness (mm)	Minimum Air Temperature (°C) Allowable for Thickness of Blanket Insulation			
	12 mm	25 mm	37 mm	50 mm
<b>Minimum Cement Content = 300 kg/m<sup>3</sup></b>				
200	5.6	0	6.1	-12
300	0	-12	-25	-37
450	-8.3	-31	-53	-75
600	-16	-48	-	-
750	-24	-	-	-
900	-33	-	-	-
<b>Cement Content = 400 kg/m<sup>3</sup></b>				
100	10	10	89	89
200	3.9	-4.4	-13	-21
300	-2.8	-18	-35	-51
450	-12	-40	-68	-95
600	-22	-61	-	-
750	-32	-	-	-
900	-42	-	-	-

**Table C9.3:** Equivalent Thickness of Insulating Materials

Insulating Material	Equivalent Thickness (mm)
25 mm Loose Fill Insulation of Fibrous Type	25
25 mm Insulating Board	20
25 mm Sawdust	15
25 mm Timber	8
25 mm Damp Sand	0.6

**(d) Removal of Forms**

In cold weather, protection offered by form other than of steel is often of greater importance. With suitable insulation, the forms, including those of steel, in many cases will provide adequate protections without supplementary heating. Therefore, it is often advantageous not to remove forms until the end of the minimum period of protection or even later. **Table C9.4** gives recommended minimum time for stripping formwork to normal structure concrete.

If these forms are not immediately required elsewhere, it is advantageous to leave them in position, as this will accelerate the hardening process and shorten the time for striking load-bearing formwork. The time limits indicated in **Table C9.4** are for general guidance only. When cubes have been stored and cured under actual site conditions, they can be used to confirm whether concrete has attained the necessary strength to allow the removal of forms.

**Table C9.4:** Recommended Minimum Time Limits for Stripping Formwork to Normal Structural Concrete, when the Member is carrying only its own weight

Cement Type	Temperature	Time (days) for stripping of forms				
		Beam sides, walls and columns	Props left under		Removal of props	
			Slabs	Beams	Slabs	Beams
Ordinary Portland Cement concrete	Cold weather air temperature about 3°C	5	7	14	14	28
	Normal weather air temperature about 10°C	1	3 ½	7	7	14
Rapid hardening Portland cement concrete	Cold weather air temperature about 3°C	3	4	8	8	16
	Normal weather air temperature about 10°C	1	2	4	4	8

**(8) Inspection, Temperature and Humidity Records**

Thermometers shall be inserted in those parts of the concrete where maximum stresses will appear at the removal of foam.

To control the hardening process, it is necessary to measure the temperature of concrete at placing, at the time of applying the protection and three times each day until resistance to freezing has been obtained. **Table C22** gives the minimum pre-hardening periods, i.e., the time taken by different grades of concrete to reach the frost safety level, the concrete being made with Ordinary Portland Cement without any accelerator. The period given in **Table C22** start from the time when the concrete first stiffens. For most medium strength structural grade concretes a reduction in the minimum pre-hardening period of 25% on those indicated in Table 2006 can be taken when using rapid-hardening Portland cement.

**(9) Concrete Testing**

Concreting in winter time requires quality control of concrete carried out with great care. Hence, the tests are prescribed.

Of special importance is knowledge on the reactivity of the cement and control of the setting time of the cement. In addition, it is important to ensure that water cement ratio does not exceed the design value. When air-entraining agents are used, the air content shall also be controlled.

Under normal concreting conditions, test specimens are cast and cured in a standard way to indicate the potential strength properties of the concrete mix. It is recommended that before the job is started, preliminary tests are carried out in the laboratory of the selected concrete mix, cured at 5°C.

In addition to cubes, it is necessary to cast a number of specimens the curing conditions of which are arranged in such a way that they are exposed to the same temperature and humidity conditions as the actual structure and preferably similar to those of the most exposed parts. These specimens are tested before tripping takes place to ensure that the indications of strength development obtained by temperature measurements are in fact obtained.

Also, it is necessary that similarly cured specimens are kept in the moulds until testing takes place, to prevent drying out of the specimen.

### C(c) Under-Water Concreting

Concrete cast under water shall not fall freely through the water. If it falls freely through the water, it may leach and segregate.

Inspection of concrete during placement under water is difficult. Therefore, it is essential to evaluate the proposed mix proportions, inspect the equipment and review preparation prior to the start of underwater concreting. The indicated slump of 100 to 180 mm applies to placing by tremie. Dewatering while the concrete has not hardened sufficiently may disturb the concrete and may lead to undesirable results. Also, freely falling concrete under water undergoes leaching and segregation.

The details of the methods of depositing concrete under water are:

#### (i) Tremie Concreting

Concrete is placed through vertical pipes, the lower end of which is always inserted sufficiently deep into the concrete which has been placed previously, but has not set. The concrete emerging from the pipe pushes the material that has already been placed sideways and upwards and thus does not come into direct contact with water.

When concrete is to be deposited by means of tremie, the top section of the tremie shall be a hopper large enough to hold one entire batch of the mix or the entire contents the transporting bucket, if any. The tremie pipe shall be not less than 200 mm in diameter and shall be large enough to allow a free flow of concrete and strong enough to withstand the external pressure of the water in which it is suspended, even if a partial vacuum develops inside the pipe. A flanged steel pipe shall be used, which has adequate strength for the site conditions. A separate lifting device shall be provided for each tremie pipe with its hopper at the upper end. Unless the lower end of the pipe is equipped with an approved automatic check valve, the upper end of the pipe shall be plugged with a wadding of the gunny sacking or other approved material before delivering the concrete to the tremie pipe through the hopper, so that when the concrete is forced down from the hopper to the pipe, it will force the plug (and along with it any water in the pipe) down the pipe and out of the bottom end, thus establishing a continuous stream of concrete. It will be necessary to raise slowly the tremie in order to cause a uniform flow of the concrete, but the tremie shall not be emptied so that water enters the pipe. At all times after the placing of concrete is started and until all the concrete is placed, the lower end of the tremie pipe shall be below the top surface of the plastic concrete. This will cause the concrete to build up from below instead of flowing out over the surface, and thus avoid formation of laitance layers. If the charge in the tremie is lost while depositing, the tremie shall be raised above the concrete surface, and unless sealed by a check valve, it shall be re-plugged at the top end, as at the beginning, before refilling for depositing concrete.

The buoyancy of the empty pipe (of the tremie) is frequently a problem when concrete is to be placed through 20 m or more of water. When this problem occurs, it may be desirable to start concreting with water in the pipe. In this case also, the upper end of the pipe should

be plugged with a snugly fitting ball made up of gunny sacking before delivering the concrete to the hopper. The void content of the coarse aggregate should be kept as low as possible. The clause assumes a maximum void content of 55%.

(ii) *Direct placement with pumps*

As in the case of the tremie method, the vertical end piece of the pipe line shall be inserted sufficiently deep into the previously cast concrete and shall not move to the side during pumping.

(iii) *Drop bottom bucket*

The top of the bucket shall be covered with a canvas flap. The bottom doors shall open freely downward and outward when tripped. The bucket shall be filled completely and lowered slowly to avoid backwash. The bottom doors shall not be opened until the bucket rests on the surface upon which the concrete is to be deposited and when discharged, shall be withdrawn slowly until well above the concrete.

(iv) *Bags*

Bags of at least 0.028 m<sup>3</sup> capacity of jute or other coarse cloth shall be filled about two-thirds full of concrete, the spare end turned under so that bag is square ended and securely tied. They shall be placed carefully in header and stretcher courses so that the whole mass is interlocked. Bags used for this purpose shall be free from deleterious materials.

(v) *Grouting*

A series of round cages made from 50 mm mesh of 6 mm steel and extending over the full height to be concreted shall be prepared and laid vertically over the area to be concreted, so that the distance between centers of the cages and also to the faces of the concrete shall not exceed 1m. Stone aggregate of not less than 50 mm nor more than 200 mm size shall be deposited outside the steel cages over the full area and height to be concreted with due care to prevent displacement of the cages. A stable 1:2 cement-sand grout with a water-cement ratio of not less than 0.6 and not more than 0.8 shall be prepared in a mechanical mixer and sent down under pressure (about 0.2 MPa) through 38 to 50 mm diameter pipes terminating into steel cages, about 50 mm above the bottom of the concrete. As the grouting proceeds, the pipe shall be raised gradually up to a height of not more than 6m above its starting level after which it may be withdrawn and placed into the next cage for further grouting by the same procedure. After grouting the whole area for a height of about 600 mm, the same operation shall be repeated, if necessary, for the next layer of 600 mm and so on. The amount of grout to be sent down shall be sufficient to fill all the voids which may be either ascertained or assumed as 55 percent of the volume to be concreted.

(iv) *Precast Concreting*

Precast members should be preferred, because then it will be possible to achieve dense concrete and eliminate those with porous or defective concrete by inspection before installation. Unreinforced elements should be used if practicable, as reinforcing steels are susceptible to corrosion caused by chlorides present in sea water.

(vii) *Construction Joints*

Construction joints are potentially weak and the problems of durability are accentuated in the zone subject to alternate drying and wetting that is, between upper and lower planes of wave action. **IS 4082** recommends a coat of cement water over the reinforcing steels stored in coastal areas.

For under water concreting admixtures are frequently used to improve the flowability of the mix. Water reducing or water reducing and retarding admixtures are particularly beneficial in reducing water demand to provide a cohesive yet high slump concrete. To maintain the workability as high as possible for a longer possible duration retarding admixtures are beneficial in a large monolithic placement. Also, admixtures are available to prevent washout of cementitious materials and fines from concrete to be placed under water. For underwater concreting, the use of *anti-washout admixture* is found to be effective. Anti-washout admixture increases the viscosity of concrete and prevents its component

materials separating even in water during placement. Generally, mineral admixtures are used to improve the flow of concrete and to maintain the cohesiveness of mix despite its high workability.

#### **C(c) Concreting in Aggressive Soils and Water**

The clause refers primarily to concretes placed in soils and waters, containing sulphates, nitrates and other salts which may cause deterioration of concrete. Naturally occurring aggressive chemicals (such as sulphates of sodium and magnesium) are sometimes found in soils and waters. Sea water is mildly aggressive to concrete because of the soluble sulphates it contains. The decomposition of sulphide minerals contained in colliery waters may result in the formation of  $\text{Fe}_2\text{SO}_4$ , which can cause severe sulphate attack. Durability problems arise when concrete is exposed to acids.

Two types of precautions are given in the Code:

- (1) Those in which proper attention to concrete itself will provide sufficient immunity.
- (2) Those in which additional precautions are taken to prevent contact between aggressive chemicals and concrete.

The destructive action of aggressive waters on concrete is progressive. The rate of deterioration decreases as the concrete is made stronger and more impermeable, and increases as the salt content of the water increases. Where structures are only partially immersed or are in contact with aggressive soils or waters on one side only, evaporation may cause serious concentrations of salts with subsequent deterioration, even where the original salt content of the soil or water is not high. High concentrations are those in which the total  $\text{SO}_3$  in soil is over 1% and the sulphate in ground water, expressed as  $\text{SO}_4$ , is over 250ppm, i.e., beyond the upper limits of Table 20. Whenever acids and high concentrations of sulphates are anticipated, Portland cement concrete should be protected from exposure to these aggressive agents.

A reduction in water-cement ratio and an increase of cement content is recommended for partially immersed structures and for those in contact with aggressive agents on one side only.

#### **C(d) Mass Concreting**

Mass concrete is any volume of concrete with dimensions large enough to require that measures be taken to cope with the generation of heat from hydration of the cement and attendant volume change to minimize cracking. The one characteristic that distinguishes mass concrete from other concrete work is *thermal behavior*. The cement-water reaction causes the temperature to rise within a large concrete mass, and where the heat is not quickly dissipated, can be quite high. Significant tensile stresses and strains may result from the restrained volume change associated with a decline in temperature as heat of hydration is dissipated.

## 92.2 Reinforcing Steel Bars

Reinforcing steel shall be *cut, fabricated* and *assembled*, as per provisions indicated hereunder.

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### C92.2 Reinforcing Steel Bars

The behaviour of reinforcing steel depends on how the bars are *cut, fabricated* and *assembled*. To ensure good quality control in all reinforced and prestressed concrete structures, these operations are standardised.

### 92.2.1 Cutting

Reinforcing bars shall be cut to length by:

- (1) *Shearing*, when the diameter of the bar is 12 mm or smaller, and
- (2) *Sawing*, when diameter of the bar is 16 mm or larger.

The following shall not be permitted:

- (1) Cutting by burning with oxyacetylene equipment, and
- (2) Heating of reinforcing bars for bending or straightening.

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### C92.2.1 Cutting

Significantly larger effort is required to *shear* a 16mm bar than a 12 mm bar. Even if done, the sheared ends of the bar are not clean *planar surfaces*. Hence, shearing of large diameter bar is not permitted.

Also, *heating* changes the characteristics of the steel. This weakens the bars by making them brittle and dangerous to handle. Such bars do not serve the intended purpose, because they do not have the characteristic strength after the heat treatment.

#### 92.2.2 Fabricating

Bars should be bent in accordance with IS 2502:1963. All bars shall be bent in ambient temperate conditions (called as *cold condition*). Proper bending tools shall be used, thus guarding against notching of the bars. Bent bars are then checked to insure that lengths, depths, and radii are correctly reproduced, as per the bending details shown on the construction drawings.

The use of hand bending tools is limited to making adjustments during placing. The minimum diameter  $\Phi$  of mandrel over which a bar of diameter  $\phi$  shall be bent shall be taken as specified in **IS 1786**.

Steel bars shall not be *re-bent*. In particular, the no dowels shall be left (by bending it into the formwork to stay on the surface of the member) for continuing the construction to stay within the formwork and straightened after the forms are removed.

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#### C92.2.2 Fabricating

Re-bending creates work-hardened areas, which change adversely the performance of the bar. The mandrel diameter  $\Phi$  depends on the maximum elongation strain that the bar can sustain. Small total elongation requires large mandrel diameter  $\Phi$ , as per the expression:

$$\Phi = \frac{\phi}{\varepsilon_{elong,max}},$$

where  $\phi$  is the diameter of the bar being bent.

**92.2.3 Assembling**

Assembling of reinforcing steel shall be as per the IS 2502: 1963. The spacing of ties in concrete structures shall be sufficient to prevent shifting of bars during placing of concrete. The main and stirrup reinforcing steel shall be assembled (preferably) outside the formwork, and then the assembled grill placed lowered into the position inside the formwork.

Reinforcement detailing shall be such that:

- (1) It permits compaction by insertion of the needle vibrator; and
- (2) No two steels, which are *manufactured by different methods*, are required to be in contact with each other.
- (3) They shall not be bent aside at construction joints and bent back afterwards into their intended positions.
- (4) They shall be placed and tied in such a way that concrete placement be possible without segregation of the mix.

When the reinforcing detailing scheme shown on the construction drawings does not meet the above two requirements, the said *drawings* shall be referred back to the *structural designer* for providing a revised detailing scheme meeting the above requirements.

Bar bending schedules prepared for all reinforcement work (in keeping with the procedure specified in **IS 2502**) shall comply with the following:

- (1) All reinforcement shall be placed and maintained in the position shown in the drawings by providing proper cover blocks, spacers, supporting bars, etc.
- (2) Crossing bars should not be tack-welded for assembly of reinforcement.
- (3) The high strength deformed steel bars shall not be re-bent.

**(a) Placing of Reinforcement**

Rough handling, shock loading (prior to embedment) and the dropping of reinforcement from a height shall not be permitted.

**(b) Tolerances on Placing of Reinforcement**

Reinforcement bars shall be secured against displacement outside the specified limits. Spacers, chairs and other supports detailed on drawings, together with such other supports as may be necessary, shall be:

- (1) Used to maintain the specified nominal cover to the steel reinforcement,
- (2) Placed at a maximum spacing of 1 m or closer, and
- (3) Made of *concrete* of same strength or of *PVC*.

In any case, Spacers, chairs and other supports shall be placed in the formwork within the following tolerance on clear cover:

- (1)  $\pm 5$  mm, when specified clear cover is 30 mm or less, and
- (2)  $\pm 10$  mm, when specified clear cover is more than 30 mm.

**(d) Welded joints or Mechanical Connections**

Reinforcement bars shall not be welded. Splicing bars of can be done by:

- (1) Lapping, when diameter of bar is 12mm or less, and
- (2) Only by use of mechanical couplers (complying with **IS 16172**), when diameter of bar is 16mm or more; Tests shall be conducted on such samples of bars coupled mechanically to prove that the splice is able to provide full strength in connected bars.

**Decide on the use of Headed Connection at the end of the longitudinal bar for anchorage. Include it in the design chapter also.**

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### C92.2.3 Assembling

Procedures for bending and fixing of reinforcement bars are given in **IS2502**. Reinforcement bars should be bent cold. Considering that bars of diameter more than 25 mm require large effort to bend when cold. In such cases, the bars may be bent in the plant itself in hot at cherry-red heat (not exceeding 550°C). But this may be impractical for most projects whose reinforcement detailing is unique. Bars of diameter 12 mm and less may be bent by using simple *hand tools* (such as a *claw*), those of diameter 16mm by a simple hand held machine (without gears), and those of larger diameters by a geared bar-bending machine (hand operated). For bars if diameter 36mm and more, or where large quantities of bars are to be bent, power-operated benders may be used. The tolerance for bending and cutting are also specified in **IS 2502**.

Bars crossing each other should be secured by annealed binding wires (0.9mm diameter or over) at intervals, such that they will not slip over each other during concreting. Bars should be free to act along with concrete in the direction in which they are provided without any lateral restraint. Permissible deviations from specified dimensions of cross-sections of beams and columns are given in **Clause \_\_\_\_**. Allowances for tolerances for bending and fixing of reinforcements should be based on **Clause \_\_\_\_**. Cover to reinforcement is liable to variation on account of errors in dimensions of formwork and the cutting, bending and fixing of the reinforcement. The dimension corresponding to the cover, shown in the drawing is the nominal cover. All reinforcement should be fixed to this nominal cover, using spacers of the same size as the nominal cover. The term nominal cover implies usually a permissible negative tolerance of 5 mm, *i.e.*, the actual cover could be 5 mm less than the nominal cover. When a reinforcing bar is to be bent between two concrete faces, *e.g.*, a rectangular stirrup or link, sufficient cover to steel bars in the concrete is important to protect the bars from fire hazards, possibility of corrosion, and exposure to weather.

Welding close to a bend portion of a large size bar has the effect of accelerating the strain-ageing which follows the bending, and this in turn reduces the ductility of the section. Welding of any kind has deleterious effects on the reinforcement, when it is located in a section of the work subject to excessive fatigue or impact forces. The latter forces may occur during erection of precast units. In any type of welding, the ability of the workman determines the quality welds. The fatigue strength of beams in which the links have been welded to the main bars can be reduced by as much as 50%. Therefore, welding are prohibited in reinforcing steel of concrete structures.

Within the concrete mass, different types of metal in contact should be avoided to ensure that bimetal corrosion does not take place.

### 92.3 Prestressing Steel Tendons

Prestressing steel tendons shall be *cut, fabricated* and *assembled*, as per provisions indicated hereunder.

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#### C92.3 Prestressing Steel Tendons

The behaviour of prestressing steel tendons depends on how the bars are *cut, fabricated* and *assembled*. To ensure good quality control in all prestressed concrete structures, these operations are standardised.

### 92.3.1 Cutting and Placing

All cutting to length and trimming of the ends of wires or strands shall be done by suitable mechanical cutters. Under factory conditions, flame cutting may be permitted. Tendons shall be ordered preferably to the exact length required. Any trimming required shall be done only after the tendon has been tensioned and the grout has set.

#### (a) Straightness

- (1) The wire or strand, as supplied, shall be self-straightening when uncoiled.
- (2) In high tensile alloy steel bars, any straightening shall be carried out by mechanical means. Bars shall not be bent when their temperature is less than 10°C.
- (3) In no case, heat shall be applied to facilitate straightening or bending of prestressing steel.

#### (b) Arrangement and Positioning

- (1) All prestressing steel shall be carefully and accurately located in the exact positions shown in the design drawings. The permissible tolerance in the location of the prestressing tendon shall be  $\pm 5$  mm. Curves or bends in prestressing tendon required by the designer shall be gradual and the prestressing tendon shall not be forced around sharp bends exceeding 1 in 6 both in plan and elevation or be formed in any manner that is likely to set up undesirable secondary stresses. The minimum radius of curvature for curved cables shall be specified to ensure that bursting of side cover both perpendicular to the plane of curvature and in the plane of the ducts do not take place.
- (2) The relative position of prestressing steel in a cable shall be maintained by suitable means such as sufficiently rigid and adequately distributed spacers.
- (3) The internal cross-sectional area of duct shall generally be 2.5 to 3 times the nominal area of prestressing tendons to ensure free flow of grout.
- (4) The method of fixing and supporting the steel in the mould or the formwork shall be such that it is not displaced during the placing or compaction of the concrete or during tensioning of the steel.
- (5) The type of fixtures used for positioning the steel shall be such that it does not give rise to friction greater than that assumed in the design.

#### (c) Jointing

- (1) Coupling units and other similar fixtures used in conjunction with the prestressing steel shall have an ultimate tensile strength of not less than the individual strengths of the wires or bars being joined.
- (2) High tensile wire other than hard-drawn wire may be joined together by suitable means provided the strength of such joints is not less than the individual strengths of the wires being joined. Hard-drawn wire used in prestressed concrete work shall be continuous over the entire length of the tendon.
- (3) High tensile steel bars may be joined together by means of couplings, provided the strength of the coupling is such that in a test of destruction, the bar shall fail before the coupling.
- (4) Welding shall not be permitted in prestressing steel.

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### C92.3.1 Cutting

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### 92.3.2 Laying in Sheathing Ducts

In all constructions of the post-tensioned type, whether prestressing is subsequently bonded or not bonded with concrete, the anchorages, prestressing steel sheathing material forming ducts in concrete and anchorages shall be given adequate protection against corrosion at all stages of construction and during service life.

#### (a) Construction with unbonded steel embedded in concrete

For protection of sheathing material forming ducts, the durability requirements shall be followed. Furthermore, the internal surface of duct, prestressing steel and anchorage shall be protected by following methods in suitable combination depending upon severity of environment and extent of layers of protection considered desirable:

- (1) Coating of steel and duct by reactive metals, like zinc (Zn) or zinc plus aluminium (Zn + Al), preferably applied by hot dipping method.
- (2) Use of non-corroding sheath material, like high density polyethylene and fibre reinforced plastic.
- (3) Coating of steel by non-reactive materials, like epoxy (factory applied).
- (4) Covering individual uncoated steel or coated steel strands/wires in sheaths formed by extrusion process in factory using non-corroding material, like HDPE or similar. The space between sheathing and duct can be filled with corrosion inhibiting materials, like grease and wax.
- (5) In case of large size prestressing units, use of protective and replaceable corrosion inhibition material for grouting the ducts, such as grease, wax polyurethane foam, wherein any corrosive trace elements, shall be controlled to remain within acceptable limits. Systems for checking the efficacy of the method during service life and provisions for replacing/ making up loss of filler material shall be incorporated.
- (6) External parts of anchorages and projecting cables shall be covered by suitable casing and protected by suitable material and method.

For selection of appropriate method, material specifications, installation process, etc, specialist literature should be referred to.

#### (b) Construction with unbonded steel and anchorages not embedded in concrete

(external prestressing elements)

The methods given in **Clause 92.3.2** shall be applicable for this type of construction also. In addition, the material, strength and environmental resistance of the ducts forming external enclosure shall provide adequate mechanical strength and stability against environmental attack, including solar radiation. The ducts shall be strong enough to resist pressure from the grouting operations.

#### (c) Construction with post-tensioned bonded prestressing steel

Internal prestressing sheathing material as well as prestressing steel is protected by dense alkaline concrete cover, which shall be of quality and thickness as specified. The steel inside ducts is best protected in long terms by cement grouts, which are properly executed as per **Clause 92.3.2**. The protection by grouting can be further augmented by use of methods given below:

- (1) Use of coated steel using Zn, Zn+, Al or epoxy, and
- (2) Use of non-corroding impervious sheathing material, like HDPE. But, bond between sheathing and concrete and sheathing and grout shall be adequate as needed by design. This method is particularly suitable in presence of migrating water or variable drying/wetting condition of concrete of severe external penetration of corrosive agents. External parts of anchorages and projecting cables should be covered by suitable casing and protected by suitable material and method.

**(d) Protection during construction period**

- (1) The prestressing steel, sheathing and anchorages shall be manufactured, transported and stored at site in such a way as to provide them with adequate corrosion protection. Use of proper packaging and provision of externally applied passivating agents, oil films, *etc*, which is carried over in factory itself is recommended.
- (2) If prestressing steel or metallic sheathing material is left unprotected at site or embedded in concrete during construction period longer than two weeks, it shall be protected by flushing with oil-water mixture (*e.g.*, cutting oil) with periodic reflusing at not more than three months interval.
- (3) After stressing, the sheaths or steel shall be provided with permanent protection as soon as possible, preferably within one week. While providing protection by pressure grouting of cement, care shall be taken that the neighbouring cables are not penetrated by grout. In case of doubt, such cables shall be grouted in immediate sequence before the earlier grout could have set. If the earlier stressed cables are not grouted to avoid this problem, they shall be protected by periodic flushing by oil-water mixture as given in (2) above.

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**C92.3.2 Laying in Sheathing Ducts**

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### 92.3.3 Prestressing

The provisions hereunder shall be applicable to prestressing processes.

#### (a) Equipment

##### (1) Tensioning Apparatus

These requirements shall apply to both the pre-tensioned and the post-tensioned methods of prestressing concrete except where specifically mentioned otherwise.

- (i) Prestressing steel may be tensioned by means of hydraulic or mechanical jacks. The tension apparatus shall be such that it facilitates measurement and control of application of force. The tensioning apparatus shall be independently supported so that it does not induce any undesirable secondary stresses.
- (ii) The anchorage provided for the temporary gripping of tendons on the tensioning apparatus shall be secured such as not to damage the tendon.
- (iii) Devices attached to the tensioning apparatus for measuring the applied force shall be such that they do not introduce errors exceeding 5%.

##### (2) Temporary Gripping Device

Prestressing tendons may be gripped by wedges, yokes, double cones or any other approved type of gripping devices. The prestressing wires may be gripped singly or in groups. Gripping devices shall be such that in a tensile test, the wire or wires fixed by them would break before failure of the grip itself.

##### (3) Releasing Device

The releasing device shall be so designed that during the period between the tensioning and release, the tension in the prestressing elements is fully maintained by positive means, such as external anchorages. The device shall enable the transfer of prestress to be carried out gradually so as to avoid large difference of tension between wires in a tendon, severe eccentricities of prestress or the sudden application of stress to the concrete.

##### (4) Anchorage Device

The anchorage device may be patented or otherwise, which complies with the requirements laid down under 13.1.4.2 to 13.1.4.5.

- (i) The anchoring device shall be strong enough to resist in all respects a force equal to at least the breaking strength of the prestressing tendon it anchors.
- (ii) The anchorage shall transfer effectively and distribute, as evenly as possible, the entire force from the prestressing tendon to the concrete without inducing undesirable secondary or local stresses.
- (iii) The anchorage shall be safe and secure against both dynamic and static loads as well as against impact (see Annex C).
- (iv) The anchorage shall have provision for the introduction of a suitable protective medium, such as cement grout, for the protection of the prestressing steel unless alternative arrangements are made.

#### (b) Procedure for Tensioning and Transfer

##### (1) Stressing

The tensioning of prestressing tendons shall be carried out in a manner that will induce a smooth and even rate of increase of stress in the tendons. The prestressing shall be controlled by measuring both the force applied to the tendon and the elongation of the tendon.

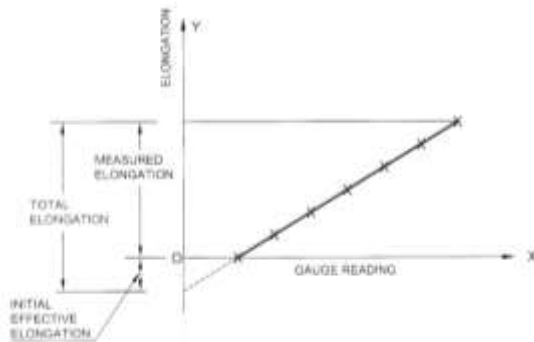
Stressing schedule shall be incorporated in the design, which may include the following:

- (i) Details of equipment and procedure for applying prestress, specification of one end or simultaneous stressing from both ends of tendons, stressing in single stage or multiple stages, re-stressing for adjustment of force or for monitoring of force, if required, etc.
- (ii) Calculated amount of tensile force and corresponding expected elongation of each tendon, when methods described in (i) above are followed.

- (iii) Minimum requirements of strength of concrete at transfer, stressing sequence with respect to age of concrete or stage of construction, requirements with respect to grouting operations of neighbouring tendons.
- (iv) Method(s) of measuring force and elongation.
- (v) Tolerances of variation from design requirements stated in (i) and (ii), beyond which reference should be made to the designer (In the absence of any specified provision provided by the designer, method described in **Clause \_\_\_\_** may be adopted for acceptance).
- (vi) Assumptions made in calculation of force elongation relationship; these include effective  $E_{sp}$  value of tendon, cross sectional area of tendon, coefficient of friction and wobble factor between tendon and duct, assumed slip in anchoring devices (if any), efficiency of prestressing jacks where force is measured indirectly by pressure gauges on jacks, corrections to elongation due to changes in gripping length beyond anchorages during stressing, and any other relevant information.

#### (2) Slack in Prestressing

Any slack in the prestressing tendon shall be overcome first by applying a small initial tension. The initial tension required to remove slackness shall be taken as the starting point for measuring elongation. Further increase of tension shall be carried out in suitable steps and corresponding elongations noted. The *force-elongation* relation shall be recorded in tabular and/or graphical form. The magnitude of initial effective elongation corresponding to initial tension applied to remove slackness shall be obtained from the recorded and linearized portion of measured tension elongation relationship and added to the measured elongation to give the total elongation. Alternatively, the same correction can be carried out graphically as shown in **Figure 9.1**.



**Figure 9.1:** Determination of actual elongation

In practice, the force and elongation of tendon may not exactly match with the expected values given in stressing schedule. In such cases either the force (or the elongation) will be achieved first and the other value lags behind. In such cases, the force (or elongation) shall be further increased, but not exceeding 5% of the design value till the elongation (or force), which had lagged behind reaches the design value. If, even after reaching 5% extra value of the force (or elongation), the other lagged quantity does not reach the design value, reference shall be made to the designer for review and corrective action.

When two or more prestressing wires or strands are to be tensioned simultaneously by the same tensioning apparatus, care shall be taken to ensure that all such tendons are of the same length from grip to grip.

The placement of tendons and the order of stressing and grouting shall be so arranged that the prestressing steel, when tensioned and grouted, does not adversely affect the adjoining ducts.

(3) *Measurement of Prestressing Force*

The force induced in the prestressing tendon shall be determined by means of gauges attached to the tensioning apparatus as well as by measuring the extension of the steel. It is essential that both methods are used jointly so that the inaccuracies to which each is singly susceptible are minimized. Due allowance shall be made for the frictional losses in the tensioning apparatus.

All dynamometers and pressure gauges including master gauge shall be calibrated by an approved laboratory immediately prior to use and then at intervals not exceeding 3 months and true force determined from the calibration curve. Further, whenever there is a breakage of tendons, the calibration shall be carried out before reuse of the gauges. The pressure gauges shall be accurate within 2% of their full capacity.

In measuring the extension of prestressing steel, any slip which may occur in the gripping device shall be taken into consideration.

(4) *Breakage of Wires*

The breakage of wires in any one prestressed concrete member shall not exceed 2.5% during tensioning. If the breakages are more than 2.5%, it shall be examined and corrective actions taken. Wire breakages after anchorage, irrespective of percentage, shall not be condoned without special investigations.

(5) *Transfer of Prestressing Force*

The transfer of the prestress shall be carried out gradually so as to avoid large differences of tension between wires in a tendon, severe eccentricities of prestressing force and the sudden application of stress to the concrete.

Where the total prestressing force in a member is built up by successive transfers to the force of a number of individual tendons on to the concrete, account shall be taken of the effect of the successive prestressing.

In the long line and similar methods of prestressing, when the transfer is made on several moulds at a time, care shall be taken to ensure that the prestressing force is evenly applied on all the moulds, and that the transfer of prestress to the concrete is uniform along the entire length of the tension line.

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C92.3.3 *Prestressing*

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#### 92.3.4 Grouting

The equipment required for grouting and the process of grouting shall be as specified hereunder.

##### (a) Equipment

###### (1) Grout colloidal mixer

Grout shall be continuously mixed in a colloidal mixer with a minimum speed of 1,000 rpm and travel of discharge not exceeding 15 m/s.

###### (2) Grout pump

The pump shall be of *positive displacement type*, and should be capable of injecting the grout in a continuous operation and not by way of pulses. The grout pump shall be fitted with a pressure gauge to enable pressure of injection to be controlled. The minimum pressure at which grout should be pumped shall be 0.3 MPa, and the grout pump shall have a relief arrangement for bypass of the grout in case of built up of pressure beyond 1.0 MPa. The capacity of the grout pump shall be such as to achieve a forward speed of grout of around 5–10m/min.

Use of hand pumps and compressed air operated equipment for injection of grout shall not be permitted.

###### (3) Water pump

Before commencement of grouting, a stand-by direct feed high pressure water pump should be available at site for an emergency.

In case of any problem in grouting the ducts, such pump shall immediately be connected to the duct and all grout flushed by use of high pressure water flushing. Therefore, it is necessary to have adequate storage of clean potable water for operation of the water pump for such emergencies.

###### (4) Grout screen

The grouting equipment shall contain a screen having a mesh size of IS Sieve No. 106 (IS Sieve No. 150, if sand is used). Prior to introduction into the grout pump, the grout shall be passed through such screen. This screen shall be easily accessible for inspection and cleaning.

###### (5) Connections and air vents

Standard details of fixing inlets, outlets, and air vents to the sheathing and/or anchorage shall be followed as recommended by specialist supplier of the system of prestressing. In general, all connections shall be of the *Quick Couple* type and suitable reducers provided at change of diameters.

##### (b) Mixing of Grout

Proportions of materials shall be based on field trials made on the grout before commencement of grouting, but subject to the limits specified above. The materials shall be measured by mass.

##### (c) Preparations before Grouting

The following step-wise procedure shall be adopted:

- (1) Water shall be added to the mixer, following by cement, and sand, if used. Admixture, if any, may be added as recommended by the manufacturer.
- (2) Mixing time depends upon the type of the mixer but will normally be between 2 and 3 min. But, mixing shall be for such duration as to obtain uniform and thoroughly blended grout, without excessive temperature increase or loss of expansive properties of the admixtures. The grout shall be continuously agitated until it is injected. Once mixed, no water shall be added to the grout to increase its fluidity.
- (3) Grouting shall be carried immediately after stressing the tendon, but within 2 weeks. Whenever this stipulation cannot be complied with for unavoidable reasons, adequate temporary protection of the steel against corrosion shall be taken till grouting by methods or

products which will not impair the ultimate adherence of the injected grout. For structures in aggressive environment, anchorage ends shall be sealed immediately.

- (4) Any trace of oil, if applied to steel for preventing corrosion, shall be removed before grouting operation.
- (5) Ducts shall be flushed with water for cleaning as well as for wetting the surfaces of the duct walls. Water used for flushing should be of same quality as used for grouting. It may, but, contain about 1% of slaked lime or quick lime. All water shall be drained through the lowest drain pipe or by blowing compressed air through the duct.
- (6) The water in the duct shall be blown out with oil free compressed air. As blowing out water from duct for cables longer than 50m draped up at both ends by compressed air is not effective, outlet/vent provided at or near the lowest point shall be used to drain out water from duct.
- (7) The connection between the nozzle of the injection pipe and duct shall be such that air cannot be sucked in.
- (8) All outlet points including vent openings shall be kept open prior to commencement of injection grout.
- (9) All air in the pump and hose shall be expelled before grouting. The suction circuit of the pump shall be air-tight.

#### (d) Injection of Grout

The following step-wise procedure shall be adopted:

- (1) After mixing, the grout shall be kept in continuous movement.
- (2) Injection of grout shall be continuous and uninterrupted.
- (3) Injection shall be effected from the lowest anchorage or vent of the duct, for vertical cable or cables inclined more than 60° to the horizontal.
- (4) The method of injection shall ensure complete filling of the ducts. To verify this, it is advisable to compare the volume of the space to be filled by the injected grout with the quantity of grout actually injected.
- (5) Grouting shall be commenced initially with a low pressure of injection of up to 0.3MPa, and then increased until the grout comes out at the other end. The grout shall be allowed to flow freely from the other end until the consistency of the grout at that end is the same as that of the grout at the injection end. When the grout flows at the other end, the duct should be closed and pressure built up in it. Full injection pressure at about 0.5MPa shall be maintained for at least 1 min before closing the injection pipe. It is a recommended practice to provide a stand pipe at the highest point of the tendon profile to exit all water displaced by sedimentation or bleeding. If there is a build up of pressure in excess of 1.0 MPa without flow of grout coming at the other end, the grouting operation shall be discontinued and the entire duct flushed with high pressure water. Also, the bypass system indicated in **Clause 92.3.4(a)(2)** is essential for further safety.
- (6) In the case of cables draped downwards for example, in cantilever construction simultaneous injection from both ends shall be adopted (**Figure 9.2**).
- (7) Grout not used within 30 min of mixing shall be rejected.
- (8) Disconnection shall be facilitated by a short length of flexible tube connects the duct and injection pipe. This may be squeezed and cut off after the grout has hardened.

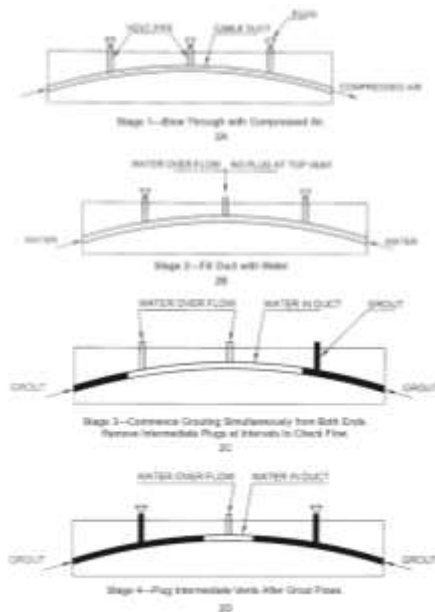
#### (e) Precautions and Recommendations for Effective Grouting

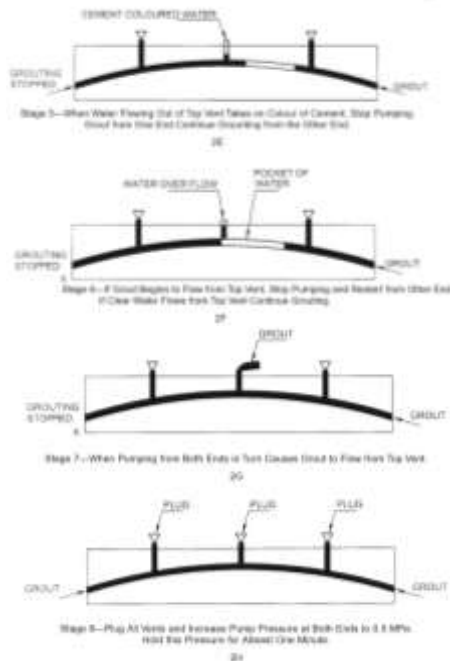
The following shall be ensured:

- (1) In cold and frosty weather, injection of grout shall be postponed unless special precautions are taken. If frost is likely to occur within 48 h after injection, heat shall be applied to the member and maintained for at least 48 h after injection, so that the temperature of the grout

does not fall below 5°C. Prior to commencement of grout, care shall be taken to ensure that the duct is completely free of frost/ice by flushing with warm water but not with steam.

- (2) When the ambient temperature during the day is likely to exceed 40°C, grouting shall be done in the early morning or late evening hours.
- (3) When the cables are threaded after concreting, the duct shall be temporarily protected during concreting by inserting a stiff rod or a rigid PVC pipe or any other suitable method.
- (4) During concreting, care shall be taken to ensure that the sheathing is not damaged. Needle vibrators shall be used with extreme care by well experienced staff only, to ensure the above requirements.
- (5) Prestressing cables shall be moved in both directions during the concreting operations. This can be done by light hammering the ends of the wires/strands during concreting. Also, 3–4 h after concreting, the cable should be moved both ways through a distance of about 200 mm. With such movement, any leakage of mortar, which has taken place in spite of all precautions loses bond with the cables, thus reducing the chance of blockages. This operation can be done also by fixing prestressing jacks at one end pulling the entire cable and then repeating the operation by fixing the jack at the other end.
- (6) The cables to be grouted shall be separated by as much distance as possible.
- (7) In case of stage prestressing, cables tensioned in the first stage shall not remain ungrouted till all cables are stressed. It is a good practice, while grouting any duct in stage prestressing, to keep all the remaining ducts filled up with water containing 1% lime or by running water through such ducts till the grout has set. After grouting the particular cable, the water in the other cables shall be drained and removed with compressed air to prevent corrosion.
- (8) Care shall be taken to avoid leaks from one duct to another at joints of precast members.
- (9) End faces where anchorages are located are vulnerable points of entry of water. They have to be necessarily protected with an effective barrier. Recesses shall be packed with mortar concrete and preferably be painted with water proof paint.
- (10) After grouting is completed, the projecting portion of the vents shall be cut off and the face protected to prevent corrosion.





**Figure 9.2:** Procedure for grouting of cables draped downwards

### C92.3.4 Grouting

#### C(a) Equipment

##### (1) Grout colloidal mixer

Grout should be maintained in a homogenous state and of uniform consistency by use of suitable agitator so that there is no separation of cement during entire grouting process. Hence, it is recommended that grout is continuously mixed.

##### (2) Grout pump

Slower rates are preferred as they reduce the possibility of occurrence of voids. If the capacity of the pump is large, it is usual to grout two or more cables simultaneously through a common manifold.

Compressed air operated equipment for injection is likely to entrap some air in grout.

#### C(c) Preparations before Grouting

- (1) The sealing of the anchorage ends after concreting is considered to be a good practice to prevent ingress of water and other gases that cause corrosion, which impair the ultimate adherence of the injected grout.

**92.3.5** *Protecting Post-Tensioned Tendons & Anchorages*  
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**C92.3.5** *Protecting Post-Tensioned Tendons & Anchorages*  
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**92.3.6** *Prestressing Methods and Arrangements*

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**C92.3.6** *Prestressing Methods and Arrangements*

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#### **92.4 Untensioned Steel Bars in Prestressed Structures**

All requirements of steel reinforcement bars in RC structures are applicable for untensioned steel in PSC structures.

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#### **C92.4 Untensioned Steel Bars in Prestressed Structures**

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### 93. QUALITY CONTROL AND QUALITY ASSURANCE

Quality of concrete structures on two factors, namely:

- (1) *Quality Control* (which exercised by the construction group), and
- (2) *Quality Assurance* (which is exercised by an independent third party peer reviewer).

The Contractor shall put in place systems for *quality control* and the Owner for *quality assurance*, to ensure a *safe, serviceable, sustainable, aesthetic and economical structure*. Quality of concrete structures depend upon total system of quality policy, quality of designs, drawings, detailing, quality control during construction, acceptance criteria, corrective action and documented systems etc..

. For the properties of the completed structure to be consistent with the requirements and the assumptions made during the *planning* and the *design*, adequate *Quality Assurance (QA)* measures shall be taken. The construction shall result in satisfactory *strength, serviceability* and long-term *durability* so as to keep the *overall life-cycle cost to a minimum*.

*QA* in construction activity relates to *ensuring*:

- (a) *Proper design*,
- (b) Use of adequate materials and components to be supplied by the producers,
- (c) *Proper workmanship* in the execution of works by the contractor, and
- (d) *Ultimately proper care* during the use of structure including *timely maintenance and repair* by the owner.

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### C93. QUALITY CONTROL AND QUALITY ASSURANCE

*Quality Control* depends on one set of factors, including total system of quality policy, quality of designs, drawings, detailing, quality control during construction, and acceptance criteria. *Competent engineers* are likely to construct structures with good *quality control*.

And, *Quality Assurance* on another set of factors, including timely inspections, immediate corrective action recommended and implemented by the construction group, and documentation of the entire system, including each detail of the process of planning, designing, constructing and maintaining of the structure. *Competent engineers with vast experience* of having constructed a large number of concrete structures are best suited to be good *quality assurance* inspectors.

### 93.1 Quality Control

~~For controlling quality of concrete structures during construction, the Owner shall implement the following Quality Control (QC) measures:~~

- ~~(1) Appoint persons competent to perform tasks in the different disciplines of the project, namely those who have:
  - ~~(a) Positive attitude,~~
  - ~~(b) Required skills to perform the tasks assigned to her/him, and~~
  - ~~(c) Good knowledge of the structure being built along with theoretical bases behind the various aspects of planning, designing, constructing and maintaining the structure, and depute periodically and proactively these persons for continuing education programs.~~~~
- ~~(2) Ensure that at least a competent person supervises the work of the younger persons with qualifications, though not competence (yet!)<sup>22</sup>.~~
- ~~(3) Establish a system to ensure that the functioning of the construction group is transparent, and the entire process of the project is documented; and~~
- ~~(4) Establish a system of internal audit of the works undertaken, to ensure timely correction and improvement in the process of construction of the project.~~

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### C93.1 Quality Control

Only competent construction groups can construct quality structures.

### 93.2 Quality Assurance

For the properties of the completed structure to be consistent with the requirements and the assumptions made during the *planning* and the *design*, adequate *Quality Assurance (QA)* measures shall be taken. The construction shall result in satisfactory *strength, serviceability* and long term *durability* so as to keep the *overall life cycle cost* to a minimum.

QA in construction activity relates to *ensuring*:

- (a) Proper design;
- (b) Use of adequate materials and components to be supplied by the producers;
- (c) Proper workmanship in the execution of works by the contractor; and
- (d) Ultimately proper care during the use of structure including timely maintenance and repair by the owner.

QA measures are both *technical* and *organizational*. Some common cases should be specified in a *general Quality Assurance Plan (QAP)*, which shall identify the key elements necessary to provide fitness of the structure and the means by which they are to be provided and measured with the overall purpose to provide confidence that the realized project will work satisfactorily in service fulfilling intended needs.

Each party involved in the realization of a project shall establish and implement a *QAP*, for its participation in the project. Supplier's and Sub-contractor's activities shall be covered in the plan. The *individual QAPs* shall fit into the *general QAP*. A *QAP* shall define the tasks and responsibilities of all persons involved, adequate control and checking procedures, and the organization and maintaining adequate documentation of the building process and its results. Such documentation shall include, generally:

- (a) Test reports and manufacturer's certificate for materials, concrete mix design details;
- (b) Pour cards for site organization and clearance for concrete placement;
- (c) Record of site inspection of workmanship, field tests;
- (d) Non conformance reports, change orders;
- (e) QC charts, wherever concrete is in continuous production over considerable period; and
- (f) Statistical analysis.

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### C93.2 Quality Assurance

The task of *Quality Assurance* should involve *quality audit* of both the inputs as well as the outputs. Inputs are in the form of materials for concrete; workmanship in all stages of batching, mixing, transportation, placing, compaction and curing; and the related plant, machinery and equipments; resulting in the output in the form of concrete in place. To ensure proper performance, each step in concreting which will be covered by the next step should be inspected as the work proceeds.

### 93.2.1 Levels of Quality Assurance

Quality inspections (with testing wherever required) shall be assured at every stage to achieving desired quality in construction. Inspections shall be carried out and appropriately documented for:

- (a) Materials to be used in concrete making,
- (b) Formwork,
- (c) Reinforcement work,
- (d) Concrete production delivery and placing, and
- (e) Post-concreting inspections.

The level of quality assurance required shall be different in different projects, depending on the importance of project, organisational setup, etc. For the purpose of this standard, the *minimum quality assurance requirements* shall be categorised under three levels, namely:

- (1) QA1: *Normal Quality Assurance Levels*,
- (2) QA2: *Moderate Quality Assurance Levels*, and
- (3) QA3: *High Quality Assurance Levels*.

The Levels of QA to be adopted in a project shall be decided by *Owner* or the *Project Authorities*. But, as guidance, minimum level of QA required for different types of structures shall be as per **Table 9.9** is as under. Higher levels can be adopted.

**Table 9.9:** Applicability of the three levels of QA in *Construction*

Level	Applicable Constructions
QA1	Structures up to 4 storey with single floor plan area not more than 500 m <sup>2</sup>
QA2	Structures up to 10 storey and single floor plan area not more than 5,000 m <sup>2</sup> , or structures of lesser size but high importance or structures with large span roofs
QA3	Structures more than 10 storey and single floor plan area more than 5,000 m <sup>2</sup> , or structures of lesser size but high importance

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### C93.2.1 Levels of Quality Assurance

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### 93.2.2 Basic Requirements of Quality Assurance

Basic Requirements of QA in different levels of QA in construction of concrete structures shall be as per **Table 9.10**. For any item specified therein, for any level of QA, requirements higher than those specified may be adopted depending upon the *type*, the *size* and the *importance* of the project.

Frequency of NDTs and Concrete Core Tests for QA3 shall be decided and specified depending on type of structure, approximate daily concrete quantity involved, *etc.* The minimum frequency recommended shall be:

- (1) One set of tests for every 100–150 m<sup>3</sup> of concrete for *Rebound Hammer Test (RHT)* and *UPV Tests*,
  - (a) For RHT, 1 set shall comprise test at 3 locations of 3 members selected randomly. At each location, 6 readings shall be taken as per **IS 516 (Part 1)**.
  - (b) For UPV, one set shall consist of three members and on each member about 1 m<sup>2</sup> of concrete surface shall be tested by cross probing.
- (2) One sample (3 cores of 60 mm diameter) for every 500–1,000 m<sup>3</sup> for *Core Test*.

**Table 9.10:** Measures in three levels of QA during Construction

S.No.	QA1	QA2	QA3
<b>1. Design and Drawings</b>			
(1)	Design office with internal QA procedures	As QA1, but with checking and reviewing by in-house or external consultants or organisations	As in QA2, but with checking and reviewing by external experts or organisations
(2)	Drawings can be <i>type-designs</i> with necessary notes to cover variations	Project specific drawings	As in QA2
(3)	As built drawings are required	As in QA1, but all changes incorporated and revised drawings issued	As in QA2
<b>2. QA Manual and QAP</b>			
	Requirements can be covered in the <i>Tender</i> , or in a standard QAP of <i>Owner</i> or <i>Consultant</i>	Specific <i>QA Manual</i> or <i>Standard Quality Manual</i> with project specific QAP, including necessary inspection, sampling and testing formats (as per <b>IS 15883</b> )	As in QA2, but with roles and responsibilities defined of all controlling Authorities mentioned in the QA Manual (as per <b>IS 15883</b> )
<b>3. Constructor</b>			
	Complying with pre-fixed requirements of experience and ability	Same as in QA1	As in QA2, but having accredited and documented <i>QA System</i> in place
<b>4. Supervision</b>			
(1)	Full-time supervision by Constructor	Full-time supervision by Constructor	As in QA2, but with pre-approved <i>site organisation chart</i> , both by <i>Constructor</i> and for <i>Secondary Supervision</i>
(2)	Secondary Periodical supervision by owner, PMC or Consultant	Full time supervision by owner/PMC/consultant	
<b>5. Quality Surveillance and Audit</b>			
(1)	By constructors qualified engineer and owners representative	As in QA1 with separate QA cell or staff of <i>Constructor</i> and <i>Owner's Representative</i>	As in QA2, but additional <i>Third Party Quality Surveillance</i> and <i>Audit</i> is essential.
(2)	Third party quality surveillance optional	Regular surveillance and audit is essential. <i>Third Party Quality Audit</i> recommended.	
<b>6. Concrete Making Material Testing</b>			
	As per <b>Clause...below</b>		
<b>7. Concrete Testing</b>			
	As per <b>Clause...below</b>		
<b>8. Concrete Mix Design and Concrete Production</b>			
	As per <b>Clause...below</b>		
<b>9. Durability Testing</b>			
	As per <b>Clause...below</b>		
<b>10. Non-Destructive Testing</b>			
	-	Recommended, but not essential	Rebound hammer and UPV Tests to be conducted at predetermined frequency to

			assess in situ strength. (Rebound hammer to be more frequently used).
<b>11. Concrete Core Test</b>			
	Only if required.	Only if required	Few locations to verify in-situ strength and to keep record as reference for use in future monitoring
<b>12. Steel Reinforcement</b>			
	As per <b>Clause...below</b>		
<b>13. Prestressing Materials and Grouts</b>			
	As per <b>Clause...below</b>		
<b>14. Any Other Item Involved in Concrete Work</b>			
	To be decided by <i>Owner</i> or <i>Engineer-in-charge</i> to ensure that material conforms to the specifications		

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**C93.2.2 Basic Requirements of Quality Assurance**

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### 93.2.3 Quality Inspections

Inspections shall examine whether or not the construction complies with the *design*. The inspection shall be in accordance with the procedure laid down for *materials, records, workmanship and other construction activities*.

Inspections before start of construction shall ensure that:

- (1) Design and detail are capable of being executed to a suitable standard, with due allowance for dimensional tolerances;
- (2) There are clear instructions for engineers on inspection standards;
- (3) There are clear instructions for engineers on permissible deviations;
- (4) Elements critical to *workmanship, structural performance, durability and appearance* are identified; and
- (5) There is a system to verify that the quality is satisfactory in individual parts of the structure, especially the critical ones.

Immediately after stripping the formwork, all concrete shall be inspected for defective work (if any) or small defects (if any) either removed or made good as applicable before concrete has thoroughly hardened.

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### C93.2.3 Quality Inspections

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### 93.2.4 Sampling and Testing of Concrete

Concrete shall be tested for performance parameters of fresh and hardened concrete, namely *workability*, *strength* and *durability* as per requirements of this standard. Tests for additional performance parameters, if any, shall be conducted as per project specific requirements, if any.

#### (a) Sampling Frequency, Testing and Acceptance Criteria

##### (i) Tests for Workability

Tests for workability shall be conducted as per **IS 1199**. Frequency of these tests shall be as per **Table 9.11**. A random sampling procedure shall be adopted to ensure that each concrete batch shall have a reasonable chance of being tested, *i.e.*, the sampling shall be spread over the entire period of concreting and cover all mixing units. Also, when concrete is supplied by a RMC plant, *workability of each truck mixer shall be checked at site immediately before use*.

**Table 9.11:** Frequency of tests for *Workability*

Quantity of Concrete in Work (m <sup>3</sup> )	Number of Samples
1-5	1
6-15	2
16-30	3
31-50	4
51 and above	4 + 1 additional sample for each additional 50 m <sup>3</sup> or part thereof

- (a) **Acceptance Criteria:** Measured values of slump shall be within the tolerances given in **Table 9.12**. When high range PC-based superplasticizers are used (which tend to give higher slump), higher tolerance on upper side may be permitted, if: (a) strength tests are satisfactory, and (b) higher variation in slumps were noticed during mix design stage also.

For other workability tests, measured slump shall be within the range specified in **Table 9.12**.

**Table 9.12:** Permissible slump in concrete

Slump Specified in Design (mm)	Permitted Tolerance in Slump (mm)
< 60	-10, +10
75 - 125	-15, +25
> 125	-20, +40

##### (ii) Tests for Strength of Concrete

- (a) **Specimen:** Tests shall be performed on cubes for assessing *compressive strength* and on beam specimen for *flexural strength*. 3 test specimens shall be made for each sample for testing at 28 days. Additional specimens may be required for various purposes, such as to: (a) determine the strength of concrete at 7 days or at the time of striking the formwork, (b) determine the duration of curing, or (c) check the testing error. Additional specimens may also be required for testing specimens cured by accelerated methods as described in **IS 9013**. The specimens shall be tested as described in **IS 516**.

Testing using 100 mm cubes of *high strength concrete*, having **MSA** of 20mm may be permitted by *Engineer-in-Charge*, if felt necessary for QC purposes and provided with a

relationship established at mix design stage. But, intermittent tests also shall be carried out regularly for confirmation with 150 mm cubes.

- (b) **Timing:** For compressive strength, samples from fresh concrete shall be taken as per IS 1199, and cubes made, cured and tested at 28 days in accordance with IS 516. To get a relatively quicker assessment of the quality of concrete, optional tests may be performed (beam specimen) by assessing modulus of rupture at  $72h \pm 2h$  or at 7 days, or compressive strength tests at 7 days may be carried out in addition to 28 days compressive strength test. For this purpose, the values shall be arrived at based on actual testing. In all cases, the 28 days compressive strength specified in Table \_\_\_\_\_ shall alone be the criterion for acceptance or rejection of the concrete in as per \_\_\_\_\_.
- (c) **Frequency of Sampling:** A random procedure shall be adopted for sampling to ensure that each concrete batch has reasonable chance of being tested, *i.e.*, the sampling is spread over the entire duration of concreting and covers all mixing units. The minimum frequency of sampling of concrete of each grade shall be in accordance with Table 9.11. Also, at least 1 sample shall be taken from each shift. Where concrete is produced at continuous production unit, such as *ready-mixed concrete plant*, frequency of sampling shall be 1 sample for every 50 m<sup>3</sup> of concrete.
- (d) **Results:** The test results of the *sample* shall be the average of the strengths of 3 *specimens*. The individual variation shall not be more than  $\pm 15\%$  of the *average strength*. If it is more, the test result of the sample shall be deemed to be *invalid*.
- (e) **Acceptance Criteria:** The concrete shall be deemed to comply with the *compressive strength* requirements when both of the following conditions are met with:
- The mean strength determined from any group of four non-overlapping consecutive test results complies with the appropriate limits of Table 9.13.
  - Any individual test result complies with the appropriate limits of Table 9.13.

The concrete shall be deemed to comply with the *flexural strength* requirements when both of the following conditions are met with:

- The *mean strength* determined from any group of four non-overlapping consecutive test results *exceeds the specified characteristic strength* by at least 0.3 MPa; and
- The strength determined from any test result is *not less than the specified characteristic strength* by 0.3 MPa.

For concrete quantity in a shift up to 30 m<sup>3</sup> (where the number of samples to be taken is less than 4) as per frequency of sampling given in 93.2.3(a)(ii)(c), the mean of test results of 4 consecutive non-overlapping samples shall be calculated (including the samples of preceding and succeeding days). Where it is not possible for small works (where total quantity involved is less than 30 m<sup>3</sup>, at least 2 samples shall be taken and no sample shall have strength less than  $f_{ck}$  and mean of 2 samples not less than  $f_{ck} + 2$ ).

The quantity of concrete represented by a group of four consecutive test results shall include the batches from which the first and last samples were taken together with all intervening batches. For the individual test result requirements given in Table 9.13 or in \_\_\_\_\_ (b), only the particular batch from which the sample was taken shall be at risk. Where the mean rate of sampling is not specified, the maximum quantity of concrete that four consecutive test results represent shall be limited to 60 m<sup>3</sup>.

If the concrete is deemed not to comply pursuant to \_\_\_\_\_ or \_\_\_\_\_ (as the case may be), the structural adequacy of the parts affected shall be investigated, and any consequential action shall be taken, as needed.

Concrete of each grade shall be assessed separately.

**Table 9.13:** Requirement for compliance of *Characteristic Compressive Strength*

Specified Concrete Grade	Minimum value of Individual Test Results (MPa)	Minimum Mean of Group of 4 Non-Overlapping Consecutive Test Results (MPa)
M10-M55	$f_{ck} - 2$	$\text{Max}[f_{ck} + 0.825\sigma; f_{ck} + 0.5X]$
M60-M100	$f_{ck} - 0.5X$	where $\sigma$ = Established Standard deviation (rounded off to nearest 0.5 MPa), and $X$ = Assumed Standard Deviation as per <b>Table 6.8</b> , when $\sigma$ is not available based on 30 samples.

**Note:** In the absence of established value of standard deviation, the values of standard deviation shall be taken from table No.....in section ..... under column (2) & (3) respectively. Attempt should be made to obtain results of 30 samples as early as possible to establish the value of standard deviation.

Concrete is liable to be rejected, if:

- It is porous or honey-combed, its placing has been interrupted without providing a proper construction joint,
- The reinforcement has been displaced beyond the tolerances specified, or
- Construction tolerances have not been met.

But, the hardened concrete may be accepted after carrying out suitable remedial measures to the satisfaction of the *Engineer-in-Charge*.

(iii) *Non-Destructive Tests during construction*

Non-Destructive Tests, wherever specified, shall be carried out as part of QA measures as per given frequency.

**(a) Acceptance Criteria:** When *Non-Destructive Tests* are to be conducted to confirm in-situ compressive strength, a relation shall be established between NDT results and cube compressive strength results at the time of mix design, this relation verified at site during field trials, and the criteria established. During routine tests:

- The average of 3 test sets shall not be less than the established value by more than 10% and,
- The result of individual set of results shall not deviate by more than 20%.

(iv) *Concrete Core Tests*

Core tests are generally conducted, when quality of concrete is in doubt and being examined. But, when specified, like in very high quality control level, limited cores (preferably of smaller diameter) can be taken from few larger size members at such locations, which do not impact the load carrying capacity of member or structure. Such a procedure shall be decided and documented in project-specific Quality Plan to be prepared **before** the start of the construction activity.

**(a) Acceptance Criteria:** When ~~Non-Destructive Tests are to be conducted to confirm in-situ compressive strength requirements, the acceptance criteria for core tests shall be same as in 93.2.3(a)(ii)(c) on compression tests. Acceptance criteria for core tests will be as per clause.... Of chapter on inspection, testing and monitoring.~~

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(v) *Durability Tests*

Tests for durability (namely resistivity, RCPT, air permeability and oxygen permeability) shall be conducted at *Mix Design* stage as well at site for *Quality Control* stage. Test to be conducted shall be as per provisions under clause 85 (Durability)

(a) **Frequency:** Frequency of tests shall be as per **Table 9.14**. At least one sample shall be taken from each shift. Where concrete is produced at continuous production unit, such as *ready-mixed concrete plant*, frequency of sampling shall be one sample for every 75 m<sup>3</sup> of concrete.

For QA3 level 3, few samples shall be extracted from structure (or from the specific extra cast mock member or specimen kept at site under similar exposure conditions) and strength tests (*RHT* and *Core Test*) conducted on them, in addition to durability tests and results preserved for use as reference in future periodical investigations on durability and service-life assessment of the structure.

(b) **Specimen:** For each test sample, three test specimens shall be prepared, and average result of the three specimens shall form one result.

(c) **Acceptance Criteria:** *Value obtained* of each result shall not deviate by more than 10% (on lower durability side) of specified value, or the value obtained at *mix design stage*, whichever is on higher side (of durability). Where there is no specified value, results shall be compared with values obtained at *mix design stage* only.

**Table 9.14:** Frequency of Test for *Durability*

Quantity of Concrete in Work (m <sup>3</sup> )	Number of Samples
1-15	1
16-50	2
51 and above	3 + 1 additional sample for each additional 75m <sup>3</sup> or part thereof

(vi) *Tests on Concrete Making Materials*

All materials to be used for concrete making shall be tested periodically to ensure that: (a) they conform to the specifications, and (b) there is no significant deviation in critical parameters with respect to the values obtained at the time of concrete mix design. When the deviation is *significant*, *appropriate adjustments* shall be made in concrete mix proportions. When the deviation is *large*, concrete mix shall be *redesigned*. The minimum frequency of various tests to be conducted on concrete making materials shall be as per **Table 9.15**.

Minimum testing of material required to generate data for mix design shall be carried out invariably at *mix design stage*, even if a particular test is not mandatory otherwise for a particular QA level.

**Table 9.15:** Measures in three levels of QA for Concrete Making Materials

Type of Test	QA1	QA2	QA3
<b>1. Cement</b>			
Physical Test	Not required, except when there is a doubt	Once for every brand and type	All lots to be tested as under;
Chemical Test	Not required, except when there is a doubt	Not required	Required
<b>2. Aggregates</b>			
Petrography and ASR Tests	Previous records may be used, or as in QA2	Once for every source	Once for every project for each source and every 500 m <sup>3</sup>
Grading Test	Every 40 m <sup>3</sup> or part thereof	Every 40 m <sup>3</sup> or part thereof	Every 40 m <sup>3</sup> or part thereof
Chemical Test		Once for every source	Once for every source and every 200 m <sup>3</sup>
Physical Test, other than Grading	Once for every source	Once for every source	Once for every source and every 200 m <sup>3</sup>
Silt content in fine aggregates	Every 20 m <sup>3</sup> or part thereof, or every stack	Every 20 m <sup>3</sup> or part thereof, or every stack	Every 20 m <sup>3</sup> or part thereof, or every stack
<b>3. Water</b>			
Physical and Chemical Tests	For each source of water, one before commencement, and every 3 month thereafter (For potable water source, one before commencement and every 6 months thereafter.)	<del>For Municipal water source, one before commencement and every 6 months thereafter.</del> For other sources, <del>As</del> in QA1	<del>One Three</del> tests for each source every one month for all sources
<b>4. Mineral Admixtures</b>			
Physical and Chemical Tests	Not required, if pre-approved for well known brand admixtures used	Same as in QA1; Manufacturer certificate for same <del>not lot is</del> valid	Every lot to be tested

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**C93.2.4 Sampling and Testing of Concrete**  
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### 93-2.5 Quality Assurance in Concrete Production

QA requirements for control during concrete production shall be as per **Table 9.16**.

**Table 9.16:** Measures in three levels of QA during *Concrete Production*

Type of Test	QA1	QA2	QA3
<b>1. General</b>			
	Site having: (a) Proper storage of cement; (b) Weigh batching of all materials; (c) Controlled addition of water; (d) Regular checking of all materials, aggregate grading and moisture content; and (e) Periodical checking of workability and strength	Same as in QA1, with automatic weigh batching plant	Same as in QA2, with (a) Moisture probes fitted to plant, (b) Batching plant with bins, (c) More frequent checking of grading and moisture content, (d) Statistical quality control charts used to monitor variation from mean
<b>2. Concrete Mix Design</b>			
	Previous mix design (with same materials) can be used  In-house Concrete Mix Design under supervision of owner or consultant permitted	Same as in QA1, but project-specific site trials needed  In-house Concrete Mix Design under supervision of owner or consultant permitted  Proper mix design report with record of materials and concrete test results	Project-specific mix design with site trials  Concrete Mix Design to be approved by Third Party  Report and Record as in QA2
<b>3. Site Trials before start (to verify Mix Design at site)</b>			
		Compressive strength is average of 4 samples, but not less than $f_{ck} + 1.65(\sigma - 1)$	Compressive strength <del>of is</del> average of 4 samples, <del>but</del> not less than <i>Target Strength</i>
<b>4. Variations in Input Materials (Concrete making materials)</b>			
	Fine aggregate of same type and in same zone as used in Mix Design.  Cement of same brand and type	Same as in QA1, with variation <u>in grading</u> limits in material properties restricted	Same as in QA2
<b>5. Review of Mix Design</b>			
	If variations in aggregate grading exceeds above limits, adjustment or revision of mix design	Same as in QA1	Same as in QA2  Also, revise or review Mix Design, when:

	needed  If cement brand different or strength issues, Mix Design to be revised		(a) Periodical mean strength less than target strength, or (b) Standard deviation observed more than assumed  Root cause analysis required for such variations
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### C93.2.5 Quality Assurance in Concrete Production

Recommended limits of variations (as *measured at site* versus *as tested at the time of Concrete Mix Design*) in some routine tests are shown in **Table C9.5**. When variations are beyond specified or recommended limits, adjustment in mix or redesign of concrete mix may be necessary.

**Table C9.5:** Acceptable limits on variations in routine tests

<i>Material</i>	<i>Property</i>	<i>Acceptable Limits</i>
Cement	28-day Compressive Strength	-5%, +5%
	7-day Compressive Strength	-7%, +7%
Coarse aggregate	Specific Gravity	- 0.055, +0.055
Fine Aggregate	Same zone with 600 micron passing	-8%, +5%
Fly Ash	45 micron passing	33%
	Fineness (Blaine's)	7%
Chemical Admixture (Superplasticiser)	Specific Gravity	1.5%
	Water reduction	5%
Concrete	Initial Setting Time	10%
	Final Setting Time	8%

### 93.2.6 Quality Assurance in Reinforcement Steel

(a) **Samples:** The samples shall be selected and examined for each lot separately for ascertaining their conformity to the requirements of the relevant specifications.

All test pieces shall be selected either:

- (i) From the cuttings of bars; or
- (ii) If, desired, from any bar after it has been cut to the required or specified size, and the test piece taken from any part of it.

The preparation of specimen shall be done in accordance with the **IS 1786**.

(b) **Frequency:** Sampling of reinforcing steel shall be done as per **Table 9.17**.

(c) **Test to be Conducted:** Physical and Chemical test shall be performed as per requirements of **IS 1786**

(d) **Acceptance Criteria:** The test results of the reinforcing steel shall be conforming to the specifications specified in **IS 1786**. Further, some provisions of retest are mentioned hereunder in case if sample fails or is rejected.

(i) *Re-Test:*

- (1) If any tensile property of any tension test specimen is less than that specified, and any part of the fracture is outside the middle-third of the gauge length (as indicated by scribe scratches marked on the specimen before testing), a retest shall be *performed*.
- (2) If the results of an original tension specimen fail to meet the minimum requirements and are within 95% of the required tensile strength, within 95 % of the required yield point, a re-test shall be performed on two random specimens for each original tension specimen failure from the lot. If all results of these re-test specimens meet the specified requirements, the lot shall be *accepted*.
- (3) If a bend test fails for reasons other than mechanical reasons or flaws in the specimen as described below, a re-test shall be performed on two random specimens from the same lot. If the results of both test specimens meet the specified requirements, the lot shall be *accepted*.
- (4) If a test specimen fails because of mechanical reason (such as failure of testing equipment or improper specimen preparation), it shall be *discarded* and another specimen taken.

**Table 9.17:** Sampling in three levels of QA during *Concrete Production*

Diameter	QA1	QA2	QA3	
All	-	At least once for all types, diameters and brands; <i>Manufacturer's Test Certificate</i> obtained and kept in record for all lots	<i>Manufacturer's Test Certificate</i> as in QA2	
			Testing of lots both for physical and chemical as under, for consignment of	
			≤ 100 Tonnes	> 100 Tonnes
< 10 mm	-	-	1 sample for every 25 tonnes	1 sample for every 40 tonnes
10 mm – 16 mm	-	-	1 sample for every 35 tonnes	1 sample for every 45 tonnes
> 16mm	-	-	1 sample for every 45 tonnes	1 sample for every 50 tonnes

**C93.2.6 Quality Assurance in Reinforcement Steel**  
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### 93.2.7 Quality Assurance in Prestressing Steel and Grout Work

**(a) Tests and Frequency:**

The tests to be conducted along with their frequency shall be as per **Table 9.18**.

**(b) Acceptance Criteria:**

All prestressing steel and other items shall meet the relevant Indian Standard specifications.

**Table 9.18:** Sampling in three levels of QA in *Prestressed Concrete work*

Tests	QA1	QA2	QA3
<b>Prestressing Cables and Strands</b>			
Physical Test to get Modulus of Elasticity, and Relaxation Test	<i>Manufacturer's Test Certificate</i>	<i>Manufacturer's Test Certificate</i> as in QA1 with additional random testing of 1 sample in every 50 Tonnes	As in QA2, with <i>Independent Third Party Agency</i> witnessing the Tests
Chemical Test		<i>Modulus of Elasticity Test</i> with stress-strain curve can be at manufacturers laboratory with <i>Project QA Team</i> witnessing it	
<b>Anchorage Assembly</b>			
Anchorage Assembly Tests	To be taken from approved proven supplier with <i>Manufacturer's Test Certificate</i>	As in QA1, with tests at manufacturers laboratory with <i>Project QA Team</i> witnessing it	As in QA2, with <i>Independent Third Party Agency</i> witnessing the Tests  Details of testing to be part of QA Plan
<b>Sheathing Ducts</b>			
	<i>Manufacturer's Test Certificate</i> from approved established or BIS certified suppliers	<i>Manufacturer's Test Certificate</i> with additional random testing from approved laboratory	As in QA2, with <i>Independent Third Party Agency</i> witnessing the Tests
<b>Grouts</b>			
	<i>Manufacturer's Test Certificate</i> from approved established or BIS certified suppliers	<i>Manufacturer's Test Certificate</i> with additional random testing from approved laboratory	As in QA2, with <i>Independent Third Party Agency</i> witnessing the Tests

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### C93.2.7 Quality Assurance in Prestressing Steel and Grout Work

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#### 94. SPECIAL CONSIDERATIONS

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#### C94. SPECIAL CONSIDERATIONS

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#### 94.1 Plain Concrete Structures

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#### C94.1 Plain Concrete Structures

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**94.2 Reinforced Concrete Structures**

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**C94.2 Reinforced Concrete Structures**

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#### 94.2.1 Construction Joints

Construction joints (also called *Cold Joints*) shall be avoided to the extent possible. If this is not possible, their number shall be minimized. Concreting shall be carried out continuously up to construction joints, the position and arrangement of which shall be indicated by the designer. Construction joints should comply with **IS 11817**.

Construction joints shall be placed at locations:

- (1) Construction joints shall not be located on the portion subjected to large shear force. The direction of construction joints is crossed at right angles to the direction of compressive force in member. When construction joints are located on the portion subjected to shear force:
  - (a) If shear resistance to be mobilized is *moderate* at the construction joint, *notches* shall be provided and the construction joint shall be reinforced appropriately; and
  - (b) If shear resistance to be mobilized is *large* at the construction joint, *shear keys* may be provided; and
- (2) Accessible to permit cleaning out of laitance, cement slurry and unsound concrete, to create rough or uneven surface. Laitance and cement slurry shall be cleaned out using wire brush on the surface of joint immediately after initial setting of concrete and to clean out the same immediately thereafter. The prepared surface shall be in a clean saturated surface dry condition, when fresh concrete is placed against it. In construction joints at locations where the previous pour has been cast against shuttering, a rough surface for the previously poured concrete shall be obtained to expose the aggregate with a high pressure water jet or any other appropriate means. Fresh concrete shall be thoroughly vibrated near construction joints so that mortar from the new concrete flows between large aggregates and develops proper bond with old concrete.

When *leaving dowels* open in structural members at a construction joint for some time before continuing the construction, precautions shall be taken. Cement slurry shall be applied on the bars during the exposed period. When steel bars are showing the signs of rusting, they shall be cleaned properly before continuing the construction. Anti-corrosive treatment may be done, if necessary.

When *continuing* construction at a construction joint, it shall be prepared to assure bond between the *old* and *new* concretes, by:

- (1) Removing thoroughly the sprayed curing membranes and release agents from joint surfaces; and
- (2) Applying an appropriate bond coat at the joint prior to placement of new concrete, which can be SBR latex-based or epoxy-based.

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#### C94.2.1 Construction Joints and Cold Joints

Construction joints are locations of discontinuity in the process or placing of concrete. These are required because it may be impractical to place concrete in a continuous operation. These should be distinguished from movement joints, including expansion joints dealt with in **Clause 84.1.5**.

Construction joints are made where the concrete placement operations at the end for the day or where one structural element is cast against previously placed concrete. Cold joints are formed primarily between two batches of concrete where the delivery and placement of the second batch has been delayed and the initially placed and compacted concrete has started to set. Joints are a common source of weakness. Hence, the clause seeks to avoid them.

Location and direction of construction joints shall be decided so as not to have any detrimental effects on the strength, the durability and external appearance of structures. The location of joints is controlled by design parameters and by construction limitations. Nevertheless, the joints should be kept as few as possible consistent with reasonable precautions against shrinkage. The spacing of construction joints is determined by the type of work, site conditions and the production capacity. Also, the construction joints should occur only where they may be properly constructed as these joints require careful attention to workmanship. From the point of view of strength of structure, it is desirable to position construction joints at points of minimum shear. Joints in load bearing walls and columns should be located on the underside of floor slabs or beams. In walls, the horizontal length of placement should not exceed 8-12 m. If there is any doubt regarding the adequacy of the bond between the old and new concrete, the reinforcement crossing the construction joint should be supplemented by dowels. The surface of hardened concrete can be made rough by sand-blasting or chipping it lightly, but the chipping should not be so vigorous that the coarse aggregates are dislodged. Laitance formed on the surface of a construction joint should preferably be removed before the concrete has hardened, but care being exercised not to disturb the young concrete too much as this is likely to leave the concrete in a porous and weak condition. Although good joints have been produced by using mortar or grout, the technique appears to present more problems than solutions; therefore, it is best avoided in most situations and place emphasis on higher compaction.

The surface of the hardened concrete should be neither *too dry* nor *too wet* with puddles of water lying on it. In the former case, excessive quantities of water may be extracted from the fresh concrete, and in the latter case, a poor bond might result. Through a similar reasoning, it can be inferred that the neat cement slurry should be of a proper consistency.

In horizontal joints, weakness may occur either at the top of concrete at the underside of the joint, or at the bottom of the concrete of the top layer. In the former case, trouble arises from the formation of laitance, especially when wet concretes incorporating finely ground cements are used. As a result, the top layer is weak, porous and less durable. At the upper side of the joints, troubles arise from an excess of aggregates and a deficiency of cement, both due to segregation. Vertical joints are more prone to shrinkage, particularly if the joint is weaker than the concrete elsewhere. Vertical stop-boards should always be provided at the ends of each section of work, to provide a surface against which the concrete can be compacted properly. Concrete should not be allowed to flow at an angle forming a feather-edge. Recommendations are given in **IS 3370 (Part 1)** for construction joints in liquid retaining structures. In the case of bins and silos, vertical construction joints are preferred (**IS 4995 (Part 2)**). No construction joints should be allowed within 600 mm below low water level or within 600 mm of the upper and lower planes of wave action, when a concrete member is to be constructed in sea water.

Protecting and preparing the construction joint is critical for maintaining the bond between old concrete and new concretes at the construction joint.

### 94.3 Prestressed Concrete Structures

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### C94.3 Prestressed Concrete Structures

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**94.3.1** *Instability during Erection*

In evaluating the slenderness effects during lifting of slender members, the following factors require consideration:

- (1) The following shall be considered: (a) Member geometry, (b) Location of lifting points, (c) Method of lifting, and (d) Tolerances in construction;
- (2) All beams, which are lifted on vertical or inclined slings, shall be checked for lateral stability and lateral moment on account of tilting of beam due to inaccuracies in location of lifting points, and due to the lateral bow.
- (3) For calculating the factor of safety  $\gamma_i$  against lateral instability, reference may be made to specialist literature;  $\gamma_i$  shall not be less than 2.
- (4) For determining the lateral moment due to tilting, realistic values which are not likely to be exceeded in practice shall be assumed for the eccentricity of lifting points and the lateral bow. The maximum tensile stress for  $\gamma_i/(\gamma_i - 1)$  times the lateral moment due to tilting shall not exceed 1.5 MPa.

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**C94.3.1** *Instability during Erection*

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**94.3.2** *Hollow Blocks and Formers*

Hollow Blocks and formers may be of any suitable material. Hollow clay tiles for the filler-type shall conform to **IS 3951 (Part 1)**. When required to contribute to the structural strength of a slab, they shall:

- (a) Be made of concrete or burnt-clay, and
- (b) Have a crushing strength of at least 14 MPa measured on the net-section when axially loaded in the direction of compressive stress in the slab.

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**C94.3.2** *Hollow Blocks and Formers*

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**94.3.3** *Precast Joists and Hollow Filler Blocks*

The construction of slabs with *precast joists and hollow concrete filler blocks* shall conform to **IS 6061 (Part 1)** and with *precast joist and hollow clay filler blocks* to **IS 6061 (Part 2)**.

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**C94.3.3** *Precast Joists and Hollow Filler Blocks*

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#### 94.3.4 Jointing of Butted Assemblies

The joints of butted assemblies shall be made of either cement grout or cement mortar or concrete. Cement grouting shall be used for joints up to 12 mm thick. For joints thicker than 12 mm and up to 75 mm, cement mortar shall be used. The mortar, which may be made of 1 part cement and 1½ parts sand, shall be of a dry consistency and shall be packed hard in layers so that it rings true. Where joints exceeding 75 mm are encountered, the joint shall be made up of concrete. Use of epoxy may be permitted with the approval of engineer-in-charge.

Further,

- (1) The stressing operations may be carried out in case of mortar joints immediately after placing the mortar but the stress in the mortar shall not exceed 7 MPa. In grouted joints and concrete joints, the allowable stress in the first 24 h after placing of the grout or concrete in the joint shall approximate as closely as possible to the strength of the grout or concrete used.
- (2) The holes for the prestressing tendons shall be accurately located and shall be in true alignment when the units are put together.
- (3) Full tensioning shall not be carried out until the strength of the concrete or mortar in the joint has reached twice the stress at transfer.

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#### C94.3.4 Jointing of Butted Assemblies

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#### 94.4 Precast Concrete Structures

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#### C94.4 Precast Concrete Structures

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### 94.5 Steel-Concrete Composite Structures

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### C94.5 Steel-Concrete Composite Structures

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