C3.1 Classes of Concrete

The classes of structural concrete to be used in the works shall be as shown on the Drawing. The mix designed properly for reference Table 3.1 may be used, in which the class designation includes two figures. The first figures indicate the characteristic strength f_{ck} at 28 days expressed in N/mm^2 and the second figure is the maximal nominal size of aggregate in the mix expressed in millimeters. Letter M in the class designation stands for Mix, letter SM stand for Special Mix.

Consistence of the mix, assessed through the Slump Test where the slump is measured in millimeters, is designate as follows:

- S: Stiff consistence, for slump ≤40
- P: Plastic consistence, for slump >40 and ≤90
- VP: Very Plastic consistence, for slump >90 and ≤150
- F: Flowing consistence for slump >150

Table 3.1 Concrete Classes and Strength (IRC 21:2000/DOR Specification)

Classes of Concrete	Consistence	Type of uses	Characteristic Strength f_{ck} (N/mm^2)	Maximum Nominal Size of Aggregate mm	Trial mixes Minimal Target Strength	Early works test cubes	
						Any one result (N/mm^2)	Average of 3 consecutive results (N/mm^2)
M 20/20	S	Ordinary	20	20	30	16	24
M 25/20	S	Ordinary	25	20	36	21	29
M 30/20	P	High Quality	30	20	42	26	34
M 35/20	P	High Quality	35	20	47	31	39
M 45/20	P	High Quality	45	20	58	41	49
M 50/20	P	High Quality	50	20	63	46	54
M 55/20	P	High Quality	50	20	69	51	59
SM 30/20	VP	Underwater	30	20	42	26	34
SM 30/20	F	Bored Piles	30	20	42	26	34
SM 45/20	P	Post-tensioned Girders	45	20	58	41	49

C3.2 Design of Proposed Mixes

Mix design shall be done under reference of IS 10262:2009, and the minimum property to be verified is as per Table 3.2.

Table 3.2 Concrete property to be verified

SN	Characteristic	Requirement	Method of Testing
1	Density	Min. 25 KN/m3	IS : 516 - 1959
2	Compressive Strength	As per Table 3.1	IS : 516 - 1959
3	Flexural strength	33% of Target f_{ck}	IS : 516 - 1959
4	Tensile splitting strength	70% of Target f_{ck}	IS : 5816-1999

Water-Cement Ratio, by weight, shall not exceed 0.40 for Reinforced Concrete, and 0.37 for Prestressed Concrete.

The contractor shall design all the concrete mixes called for in the Drawing using the ingredients which have been approved by the Engineer to achieve the strength called for in Table 3.1

Brief of IS-10262-2009-Concrete Mix Design – Indian Standard Method

The following points should be remembered before proportioning a concrete mix a per IS-10262-2009.

- This method of concrete mix proportioning is applicable only for ordinary and standard concrete grades.
- The air content in concrete is considered as nil.
- The proportioning is carried out to achieve specified characteristic compressive strength at specified age, workability of fresh concrete and durability requirements.

This method of concrete mix design consist of following 11 steps

1. Design specification
2. Testing of materials
3. Calculating target strength for mix proportioning
4. Selecting water/cement ratio
5. Calculating water content
6. Calculating cement content
7. Finding out volume proportions for Coarse aggregate & fine aggregate
8. Mix calculations
9. Trial mixing and
10. Workability measurement (using slump cone method)
11. Repeating step 9 & 10 until all requirements is fulfilled.

Let us discuss all of the above steps in detail

Step-1. Design Specifications

This is the step where we gather all the required information for designing a concrete mix from the client. The data required for mix proportioning is as follows.

- Grade designation (whether M25,M30,SM35 etc)
- Type of cement to be used
- Maximum nominal size of aggregates
- Minimum & maximum cement content
- Maximum water-cement ratio
- Workability
- Exposure conditions (As per IS-456-Table-4)
- Maximum temperature of concrete at the time of placing
- Method of transporting & placing
- Early age strength requirement (if any)
- Type of aggregate (angular, sub angular, rounded etc)
- Type of admixture to be used (if any)

Step-2. Testing of Materials as per Chapter 1

Step-3. Target Strength Calculation as per Table 3.1

Step-4. Selection of Water-Cement Ratio not exceeding upper limit mentioned above

Step-5. Selection of Water Content

Selection of water content depends upon a number of factors such as

- Aggregate size, shape & texture
- Workability
- Water cement ratio
- Type of cement and its amount

- Type of admixture and environmental conditions.

Factors that can reduce water demand are as follows

- Using increased aggregate size
- Reducing water cement ratio
- Reducing the slump requirement
- Using rounded aggregate
- Using water reducing admixture

Factors that can increase water demand are as follows

- Increased temp. at site
- Increased cement content
- Increased slump
- Increased water cement ratio
- Increased aggregate angularity
- Decrease in proportion of the coarse aggregate to fine aggregate

Maximum water content per cubic meter of concrete for nominal maximum size of aggregate : 186 for 20mm Nominal Aggregate.

Do the following adjustments if the material used differs from the specified condition.

Type of material/condition	**Adjustment required**
For sub angular aggregate	Reduce the selected value by 10kg
For gravel with crushed stone	Reduce the selected value by 20kg
For rounded gravel	Reduce the selected value by 25kg
For every addition of 25mm slump	Increase the selected value by 3%
If using plasticizer	Decrease the selected value by 5-10%
If using super plasticizer	Decrease the selected value by 20-30%

Note: Aggregates should be used in saturated surface dry condition. While computing the requirement of mixing water, allowance shall be made for the free surface moisture contributed by the fine and coarse aggregates. On the other hand, if the aggregate are completely dry, the amount of mixing water should be increased by an amount equal to moisture likely to be absorbed by the aggregate

Step-6. Calculating Cementious Material Content

From the water cement ratio and the quantity of water per unit volume of cement, calculate the amount of cementious material. After calculating the quantity of cementious material, compare it with the values given in the table shown in Step-4. The greater of the two values is then adopted.

If any mineral admixture (such as fly ash) is to be used, then decide the percentage of mineral admixture to be used based on project requirement and quality of material.

Step-7. Finding out Volume Proportions for Coarse Aggregate & Fine Aggregate

Step-8. Mix Calculations

The mix calculations per unit volume of concrete shall be done as follows.

a	Volume of concrete=	$1m^3$
b	Volume of cement=	(Mass of cement/specific gravity of cement)*(1/1000)
c	Volume of water=	(Mass of water/specific gravity of water)*(1/1000)
d	Volume of admixture=	(Mass of admixture/specific gravity of admixture)*(1/1000)

e	Volume of total aggregate (C.A+F.A)=	[a-(b+c+d)]
f	Mass of coarse aggregate=	e*Volume of coarse aggregate*specific gravity of coarse aggregate*1000
g	Mass of fine aggregate=	e*Volume of fine aggregate*specific gravity of fine aggregate*1000

Step-9. Trial Mix

Conduct a trial mix as per the amount of material calculated above.

Step-10. Measurement of Workability (by slump cone method)

The workability of the trial mix no.1 shall be measured. The mix shall be carefully observed for freedom from segregation and bleeding and its finishing properties.

Step-11. Repeating Trial Mixes

If the measured workability of trial mix no.1 is different from stipulated value, the water and/or admixture content shall be adjusted suitably. With this adjustment, the mix proportion shall be recalculated keeping the free water-cement ratio at pre-selected value.

Trial-2 – increase water or admixture, keeping water-cement ratio constant

Trial-3 – Keep water content same as trial-2, but increase water-cement ratio by 10%.

Trial-4 – Keep water content same as trial-2, but decrease water-cement ratio by 10%

Trial mix no 2 to 4 normally provides sufficient information, including the relationship between compressive strength and water-cement ratio.

C3.3 Material Quantity for Small Volume of Concrete (<20 Cum)

Table 3.3 Quantity of Materials Required for Different Grade of Concrete

Class of Concrete	Characteristic Strength (N/mm^2)	Cement (Kg)	Total Aggregate (Kg)	Fine Agg./ Total Agg. (%)	Maximum Water (Ltr)	Workability
M20/20	20	350	1875	35 - 45	160 – 170	Stiff
M30/20	30	350	1825	35 - 45	175	Plastic
M35/20	35	350	1825	35 - 45	175	Plastic

C3.4 Concrete Production

C3.4.1 Proportioning

Concrete mixes shall be proportioned according to the Design mix. Cement and aggregate shall be batched either by weight or by volume, without compromising the requirements. Water may be measured by weight or volume. The quantity of cement, each size of aggregate and water as indicated by the mechanism employed shall be *within a tolerance of plus or minus three percent of the respective weight/ volume per batch agreed by the Engineer*.

The water to be added to the mix shall be reduced by the amount of free water contained in the coarse and fine aggregates. This amount shall be determined by the Contractor by a method agreed by the Engineer.

C3.4.2 Machine Mixing

Concrete for the works shall be batched and mixed in one or more plants or concrete mixer unless the Engineer agrees to some other arrangement. If concrete mixers are used, there shall be sufficient number of mixtures including stand by mixers.

Batching and mixing plants shall be complying with the requirements of IS: 1791 and capable of producing a uniform distribution of the ingredients throughout the mass. If the plant proposed by the Contractor does not fall within the scope of IS: 1791 it shall have been tested in accordance with IS:

4634 and shall have a mixing performance within the limits of IS: 1791.

Truck mixers shall comply with the requirements of IS: 4925 and shall only be used with the prior approval of the Engineer

All mixing operations shall be under the control of an experienced supervisor

The aggregate storage bins shall be provided with drainage facilities arranged so that the drainage water is not discharged to the weigh hoppers. Each bin shall be drawn at least once per week and any accumulations of mud or silt shall be removed.

If bulk cement is used, the scale and weight hopper for cement shall be distinct from the scale and weight hopper for aggregates.

Cement and aggregates shall be batched by weight. Water may be measured by weight or volume.

The weighing and water dispensing mechanisms shall be maintained in good order.

The nominal drum or pan capacity of the mixer shall not be exceeded. The turning speed and the mixing time shall be as recommended by the manufacturer, but in addition, when water is the last ingredient to be added, mixing shall continue for at least one minute after all the water has been added to the drum or the pan.

The blades of pan mixers shall be maintained within the tolerances specified by the manufacturer of the mixer and the blades shall be replaced when it is no longer possible to maintain the tolerances by adjustment.

Mixers which have been out of use for more than 30 minutes shall be thoroughly cleaned before any fresh concrete is mixed. Mixers shall be cleaned out before changing to another type of cement.

C4.2.2 Hand Mixing

Concrete for structural purposes should not be mixed by hand. However, for small volumes of works(<20 Cum for a project), hand mixing may be carried out subject to approved of the Engineer.

For making hand mixing concrete, cement, sand and aggregate shall be batched separately by volume or by weight as applicable. Then cement and sand shall be mixed dry to uniform colour. The aggregate shall be stacked in a proper shape upon which cement sand mix shall be spread and whole mix shall be mixed to uniform consistency.

For hand mixed concrete the specified quantities of cement shall be increased by 10 % and not more than 0.25 cubic meter shall be mixed at one time. During windy weather precautions shall be taken to prevent cement from being blown away in the process of gauging and mixing.

C3.5 Transportation of Concrete

The concrete shall be discharged from the mixer and transported to the works by means which shall prevent adulteration, segregation or loss of ingredients, and shall ensure that the concrete is of the required workability at the point and time of placing. The loss of slump between discharge from the mixer and placing shall not be more than 25 mm or one third of the value whichever is the less.

The capacity of the means of transport shall not be less than the full volume of a batch.

The time elapsing between mixing transporting placing and compacting altogether of a batch of concrete shall not be longer than the initial setting time of the concrete. If the placing of any batch of concrete is delayed beyond this period, the concrete shall not be placed in the works.

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

C3.6 Placing of Concrete

C3.6.1 Preparation of Surface to Receive Concrete

Excavated surfaces on which concrete is to be deposited shall be prepared as set out in Section 900 Earthwork of DoR Yellow Book.

Existing concrete surfaces shall be prepared as set out in section C3.9. Before deposition of further concrete, they shall be clean, hard and sound and shall be wet but without any free standing water.

Any flow of water into an excavation shall be diverted through proper side drains to a sump or be removed by other suitable which will prevent washing away the freshly deposited concrete or any of its constituents. Any under drain constructed for this purpose shall be completely grouted up when they are no longer required by a method agreed by the Engineer.

Unless otherwise instructed by the Engineer surfaces against which concrete is to be placed shall receive prior coating of cement slurry or mortar mixed in the proportions similar to those of the fines proportions similar to those of the fines portion in the concrete to be placed. The mortar shall be kept ahead of the concrete. The mortar shall be placed into all parts of the excavated surface and shall not be less than 5 mm thick.

If any fissures have been cleaned out they shall be filled with mortar or with concrete as instructed by the Engineer.

The amount of mortar placed at one time shall be limited so that it does not dry out or set before being covered with concrete.

C3.6.2 Placing Procedures

The Concrete shall be deposited as nearly as possible in its final position. It shall be placed so as to avoid segregation of the concrete and displacement of the reinforcement, other embedded items or form work. *It shall be brought up in layers approximately parallel to the construction joint planes and not exceeding 300 mm in compacted thickness unless otherwise permitted or directed by the Engineer, but the layers shall not be thinner than four times the maximum nominal size of aggregate.*

As a general guidance, the maximum permissible free fall of concrete may be taken as 1.5 m.

When placing on a nearly horizontal surface, placing shall start at the lower end of the surface to avoid decompaction of concrete.

Layers shall not be placed so that they form feather edges nor shall they be placed on a previous layer which has taken its initial set. In order to comply with this requirement, another layer may be started before initial set of the preceding layer.

All the concrete in a single bay or pour shall be placed as a continuous operation. It shall be carefully worked round all obstructions, irregularities in the foundations and the like so that all parts are completely full of compacted concrete with no segregation or honey combing. It shall also be carefully worked round and between water stops, reinforcement, embedded steelwork and similar items which protrude above the surface of the completed pour.

All work shall be completed on each batch of concrete before its initial set commences and thereafter the concrete shall not be disturbed before it has set hard. No concrete that has partially hardened during transit shall be used in the works and the transport of concrete from the mixer to the point of placing shall be such that this requirement can be complied with.

Concrete shall not be placed during rain which is sufficiently heavy or prolonged to wash mortar from coarse aggregate on the exposed faces of fresh concrete. Means shall be provided to remove any water accumulating on the surface of the placed concrete. Concrete shall not be deposited into such accumulations of water.

In dry weather, covers shall be provided for all fresh concrete surfaces which are not being worked on.Water shall not be added to concrete for any reason.

When concrete is discharged from the place above its final deposition, segregation shall be prevented by the use of chutes, down pipes, trunking, baffles or other appropriate devices.

Forms for walls shall be provided with openings or other devices that will permit the concrete to be placed in a manner that will prevent segregation and accumulations of hardened concrete on the formwork or reinforcement above the level of the placed concrete.

C3.6.2.1 "CONCRETING" IN "ADVERSE WEATHER" CONDITIONS

a) 'Concreting' in "Cold" Weather

- Concrete that freezes soon after placing, gains rather low strength and some permanent damage is certain to occur. Therefore, such concrete shall be removed and replaced immediately.
- 'Planning for Protection of fresh concrete' during placement, and until it has attained the minimum properties required for the environment and the loading to which it will be exposed, shall be done well in advance of concreting and approved by the Engineer.
- Appropriate equipment shall be made available in time for heating the concrete materials, for constructing enclosures and for maintaining favourable temperatures even after the concrete is placed.
- Concrete shall never be placed on cold Forms and cold steel.

- When the temperature of these items is below 5ºC, the Contractor shall use means to raise their temperatures to above 10ºC.
- When faced with prolonged cold temperatures, all aggregates, or mixing water, or both, shall be heated to about 25ºC to 32ºC.
- At temperature at least 10ºC above freezing, it is seldom necessary to heat the Aggregates.
- At temperatures below or at freezing, often only the Fine Aggregate is heated to produce concrete of the required temperature, provided the Coarse Aggregate is free of frozen lumps and the Temperature of Water for the Mix is at least 10ºC.
- If aggregate temperatures are above freezing, the desired concrete temperature usually can be obtained by heating only the mixing water.
- Appreciable fluctuation in the mixing water temperature from batch to batch shall not be allowed.

b) 'Concreting' in "Hot" Weather:

- No concrete shall be placed when the ambient air temperature at job site in shade is expected to exceed about 35ºC during placement operations.
- When the temperature of the 'concrete mixture' is expected to exceed about 25ºC, a retarding admixture shall be included in the approved mix design since setting time tends to reduce at higher temperatures.
- The temperature of the concrete mixture immediately before placement shall not exceed 32ºC.
- When the ambient air temperature is above 32ºC, all Forms, reinforcing steel, and other contact surfaces shall be cooled to below 32ºC until concrete is placed.
- When such high ambient temperature conditions exist, the most appropriate solution is to resort to evening–night–&–morning–time concreting.
- However, if the above stated precautions are taken to help lower the temperature of contact surfaces and the concrete mix–ingredients are also cooled (explained ahead), concreting can be carried out even during day hours provided the ambient air temperature in shade does not exceed 40ºC.
- Mixers, chutes, belts, hoppers, pump lines, and other production and placement equipment can be shaded, painted white, covered with (wet) burlap, or otherwise cooled to reduce the effect of the sun's heat.
- Forms and reinforcing steel can be sprinkled with cold water and covered with wet burlap until controlled concreting commences.
- Sprinkling the area with water spray, gainfully cools the contact surfaces and surrounding air and desirably increases its relative humidity.
- This not only reduces the 'temperature rise' of the concrete but also minimizes evaporation of water from the concrete during placement and after casting.
- For slabs on ground, it is a good practice to dampen the sub-grade the evening before concreting.
- There should be no standing water or puddles on the sub-grade or inside the Forms when the concrete is placed.
- The mix water may be cooled by using shaved or crushed ice but only as much ice should be used as will be melted entirely before this water is added to the mix.
- All water used for making ice and for cooling or sprinkling, and curing, must meet the same quality requirements as those for water used for Mixing of Concrete.
- Of particular concern are the polluting sulphates and chlorides (salts) in the mix, which can adversely affect the cement and corrode the reinforcing steel, respectively. These must be kept below their specified limits.
- Aggregates should be cooled by shading and sprinkling water (fog spray).
- Transporting and placing concrete shall be done as quickly as practical during hot weather.

- Delays contribute to loss of slump, a damaging increase in concrete temperature and loss of workability.
- Enough workmen and equipment shall always be available to handle and place concrete immediately upon delivery.
- Prolonged mixing, even at agitating speed of the Drum, shall be avoided since it might heat-up the mix and reduce workability.
- If delays occur, the heat generated by continued mixing/agitating can be minimized by stopping the mixer and then agitating intermittently, but the delays shall be kept short.
- Since concrete hardens more rapidly in hot weather, extra care in placing techniques is required to avoid Cold Joints.
- For placement of Concrete in Walls, Shafts, Columns, etc., shallower layers may be required to assure proper consolidation and monolithicity with each previous lift, effective dissipation of heat of hydration and to prevent segregation of the mix.
- Temporary sunshades and windbreakers help to minimize adverse effects of hot weather, winds, and surface evaporation.

C3.6.3 Interruptions to Placing

If the concrete placing is interrupted for any reason and the duration of the interruption cannot be forecast or is likely to be prolonged, the Contractor shall immediately take the necessary action to form a construction joint so as to eliminate as far as possible feather edges and sloping top surfaces and shall thoroughly compact the concrete in accordance with section C3.7. All work on the concrete shall be completed before elapse of initial setting time and it shall not thereafter be disturbed until it is hard enough to resist damage. Plant and materials to comply with this requirement shall be readily available at all time during concrete placing.

Before concreting is resumed after such an interruption the Contractor shall cut out and remedy all damaged or uncompacted concrete, feather edges or any undesirable features and shall leave a clean sound surface against which the fresh concrete may be placed.

If it becomes possible to resume concrete placing without contravening the Specification and the Engineer consents to a resumption, the new concrete shall be thoroughly worked in and compacted against the existing concrete so as to eliminate any cold joints.

In case of long interruption concrete shall be resumed as directed by Engineer.

C3.6.4 Dimension of Pours

Unless otherwise agreed by the Engineer, pours shall not be more than1.5m high and shall as far as possible have a uniform thickness over the plan area of the pour. Concrete shall be placed to the full planned height of all pours except in the circumstances described in section C3.6.3.

The Contractor shall plan the dimensions and sequence of pours in such a way that cracking of the concrete does not take place due to thermal or shrinkage stresses.

C3.6.5 Placing Sequence

The Contractor shall arrange that the intervals between successive lifts of concrete in one section of the works are of equal duration. This duration shall not be less than three days or not more than seven days under temperate weather conditions unless otherwise agreed by the Engineer.

Where required by the Engineer to limit the opening of construction joints due to shrinkage, concrete shall not be placed against adjacent concrete which is less than 21 days old.

Contraction gaps in concrete shall be of the widths and in the locations as shown on the Drawing and they shall not be filled until the full time interval shown on the Drawing has elapsed.

C3.7 Compaction of Concrete

Concrete shall be fully compacted throughout the full extent of the placed layer. It shall thoroughly worked against the formwork and around any reinforcement and other embedded item, without displacing them. Care shall be taken at arises or other confined spaces. Successive layers of the same pour shall be thoroughly worked together.

Compact before the initial setting but not later than 30 minutes of its discharge from the mixer.

Compact concrete using internal (needle/poker) vibrators of suitable size or form vibrators, during placing and worked around the reinforcements, to produce dense, homogeneous and void free mass.

Whenever vibration has to be applied externally, the design of formwork and the disposition of vibrators should receive special consideration to ensure efficient compaction and to avoid surface blemishes.

Immersion and surface vibrators shall operate at a frequency of between 70 and 200 hertz.

A sufficient number of vibrators shall be operated to enable the entire quantity of concrete being placed to be vibrated for the necessary period and, in addition, stand-by vibrators shall be available for instant use at each place where concrete is being placed.

Vibration shall be continued at each until the concrete ceases to contract, air bubbles have ceased to appear, and a thin layer of mortar has appeared on the surface. Vibrators shall not be used to move concrete laterally and shall be withdrawn slowly to prevent the formation of voids.

The vibrators shall be inserted vertically into the concrete to penetrate the layer underneath at regular spacing which shall not exceed the distance from the vibrator over which vibration is visibly effective and some extent of vibration is overlapped.

Vibration shall not be applied by way of reinforcement nor shall the vibrator be allowed to touch reinforcement, sheathing ducts or other embedded items.

C3.8 Curing and Protection of Young Concrete

All structural concrete shall be cured for a period of time required to obtain the specified strength, but for not less than fourteen consecutive days (and nights) beginning immediately after 'initial setting' of concrete (which is when it loses its surface sheen).

Period : Regular (not less than 7 days after casting) inspection

Curing (Membrane–curing or Water–curing) of laid concrete shall be carried out as generally explained below:

Membrane–Curing the Concrete:

- Except for at Construction Joints and surfaces sealed by Forms, liquid membrane curing compound can be used (for curing the concrete) as follows:
- On bridge deck top surface and other exposed surfaces, liquid membrane curing compound shall be applied soon after Initial Setting and as the Surface Sheen has disappeared and the concrete is still slightly damp (not wet).
- On shuttered i.e. formed vertical surfaces, Forms shall be stripped as soon as practical (generally after 24 hours of casting) and liquid membrane curing compound applied immediately except in the areas that require rubbing or finishing during the curing period.
- These areas shall be kept water-wet until their finishing is completed, whereafter the liquid curing membrane shall be uniformly applied on them also when their surface is damp.
- White–pigmented liquid membrane curing compound shall be used for all surfaces where the structure temperature during curing period is likely to reach about 35ºC or more.
- For bridge decks which are to receive an asphaltic overlay, residual curing membrane (after curing) shall be removed prior to the overlaying.
- Removal methods and results should be approved by the Engineer.
- The membrane curing compound used shall be of longer lasting duration and in accordance with the requirements specified for curing membrane material, AASHTO M 148 or the equivalent IS Specification.
- The curing membrane shall be applied in two applications one immediately following the other.
- The rate of each application of curing compound shall be as prescribed by the manufacturer, with a spreading rate per application of at least one litre of liquid per five square metres of concrete surface.
- If the concrete has dried up or has become dry, it shall be thoroughly wetted with water and the curing compound applied just as the surface film of water disappears and the surface is damp.
- During curing operations any unsprayed surfaces shall be kept cured with watered Hessian cloth, and sprayed with the curing compound when Surface is damp (not wet).
- Any curing membrane material on Construction Joints and/or on reinforcing steel shall be completely removed before the following concrete pour.

- Hand operated spraying equipment shall be capable of applying constant and uniform pressure to provide uniform and even distribution of the curing membrane at the rates required.
- The curing compound shall be kept thoroughly mixed at all times during usage/application.
- No traffic of any kind shall be permitted on the curing membrane until the curing period is completed, design permitting.

Water–Curing the Concrete:

- All concrete surfaces, unless still sealed by unreleased Forms (which shall be kept from heating–up under ambient temperature) or submerged, shall be water-cured unless liquid membrane cured.
- Water curing shall begin just after initial setting of concrete (which generally occurs by about 60 minutes of placement of un-admixtured concrete and by about 120 to 180 minutes of placement of admixtured concrete) and just after the surface water sheen has disappeared.
- Surfaces water–cured shall be covered with wet sand, cotton mats, or double–thickness burlap (Jute/Hessian) sheets.
- This Hessian material shall be placed tightly around and behind any projecting reinforcing steel in order to completely cover the fresh concrete surface.
- The Hessian material shall be completely saturated with water and kept continuously saturated throughout the curing period.
- After the initial saturation, unless water is kept running, all surfaces shall be covered with thick polythene sheeting or other approved impervious material in order to protect/prevent drying-up of concrete surface being cured continuously.
- The sheeting shall be weighted down or secured well to prevent moisture–loss but the surfaces of the concrete shall be readily available for inspection of the Engineer (or his Representative).
- The sheeting material shall be in good repair.
- Sheeting that contains holes or is otherwise damaged shall be repaired or replaced immediately.
- The Contractor shall be responsible for thoroughly inspecting and monitoring the concrete surfaces throughout the curing period to ensure continuous wet curing.
- Additional water shall be poured on any areas where saturation is reduced.
- Inspection of curing by the Contractor shall be conducted at least TEN times per day and night for the duration of the curing period – and even more often if ordered so by the Engineer.
- The Engineer shall be advised of the curing inspection schedule and he (or his Representative) may accompany the workmen to verify the acceptability of curing.

C3.8.1 'COLD–WEATHER' CURING:

- When concrete is placed and the air temperature is expected to drop below 5ºC during the curing period, the Contractor shall provide suitable measures such as straw, additional burlap or other suitable blanketing materials and/or housing and artificial hot–air–curing to maintain the concrete temperature between 10ºC and 32ºC as measured on the surface of the concrete.
- The surface of the concrete shall be kept moist and warm by the use of an approved warm moisture barrier such as warm wet Burlap/Hessian.
- The moisture barrier should be maintained in intimate surface contact with the concrete during the entire curing period.
- After the completion of the curing during the entire required curing period, the Contractor shall stop the curing and remove the protection in such a manner that rapid cooling of the concrete will be prevented.
- When concrete is placed in 'cofferdams' and subsequently flooded with ground water, the above curing conditions may be waived, provided the surface of the water is not permitted to freeze/dry.

C3.9 Construction Joint

Whenever concrete is to be bonded to other concrete which has hardened, the surface of contact between the sections shall be deemed a construction joint.

Where construction joints are shown in the Drawing, the Contractor shall form such joints in such positions. The locations of joints, which the Contractor requires to make for the purpose of construction, shall be subject to the approval of the Engineer. Construction joints shall be in vertical or horizontal planes except in sloping slabs where they shall be normal to the exposed surface or elsewhere where the Drawing require a different arrangement.

Construction joints shall be arranged as to reduce to a minimum the effects of shrinkage in the concrete after placing, and shall be placed in the most advantageous positions with regard to stresses in the structures and the desirability of staggering joints.

Feather edges of concrete at joints shall be avoided. Any feather edges which may have formed where reinforcing bars project through a joint shall be cut back until sound concrete has been reached.

The intersections of horizontal and near horizontal joints and exposed faces of concrete shall appear as straight lines produced by use of a guide strip fixed to the formwork at the top of the concrete lift, or by other means acceptable to the Engineer.

Construction joints formed as free surfaces shall not exceed a slope of 20 per cent from the horizontal.

The surface of the fresh concrete in horizontal or near horizontal joints shall be thoroughly cleaned and roughened by means of high pressure water, and air jets or wire brush, when the concrete is hard enough to withstand the treatment without the leaching of cement. The surface of vertical or near vertical joints shall be similarly treated if circumstances permit the removal of formwork at a suitable time.

A Construction Joint should not be located near the centroid level of the section as here transverse SHEAR stress is highest. The Joint should be nearly perpendicular to the principal lines of tensile stress and in general be located at points of minimum Shear and minimum Moment – as far as possible.

Where dowels, reinforcing bars, or other adequate ties are not shown at Construction Joints in the Drawings, 'keys' should be formed at reasonable spacing by embedding water-soaked beveled timbers while the concrete is still soft.

These keys should be sized as may be shown in the details, or as directed by the Engineer, and these key-forming timbers shall be removed when the concrete has initially set.

The concrete surface shall then be thoroughly soaked with clean water (just before further concreting) and the free water, etc. air-blown away, and the cleaned concrete surface painted with a thin layer of cement slurry, and only then further concrete poured.

'Wire-mesh' and other similar items do not provide a proper construction joint, and they shall not be used.

In resuming concreting work, the surface of the concrete previously placed shall first be thoroughly cleaned of dirt, scum, laitance, loosely projecting aggregates and any other soft material, using stiff wire brushes, and – if deemed necessary by the Engineer – by sand blasting.

Where concrete has become too hard for the above treatment to be successful, the surface whether formed or free shall be thoroughly scabbled by mechanical means, manually or wet sand blasted and then washed with clean water. The indentations produced by scabbling shall not be less than 10 mm deep and shall be away from the finished face by 40 mm.

If instructed by the Engineer the surface of the concrete shall be thoroughly brushed with a thin layer of mortar composed of one part of cement to two parts of sand by weight immediately prior to the deposition of fresh concrete. The mortar shall be kept just ahead of the fresh concrete being placed and the fresh layer of concrete shall be thoroughly and systematically vibrated to full depth to ensure complete bond with the adjacent layer.

No mortar or concrete shall be placed until the joint has been inspected and approved by the Engineer.

COLD JOINTS:

When a planned 'continuous' placement of concrete in any structural member is interrupted or delayed, for any reason, for a period long enough for the previously partially placed concrete to take its initial set, the Engineer may declare such a joint as a Cold Joint and the Contractor shall immediately remove the previously partially placed concrete from the Forms.

However, where feasible, the previously partially placed concrete may instead be suitably and carefully hacked and its hacked end brought into 'low shear low moment' zone as far as possible, and given shear key depressions after bringing it nearly perpendicular to the principal lines of tensile stress (for example: brought to vertical or nearly vertical in a beam with principal bending reinforcement horizontal) and thereafter same treatment shall be given to it as to a Construction Joint and only then the concreting resumed (making sure all reinforcements are as per the approved Drawings and the Shuttering has been brought to line and plumb tightly).

C3.10 Records of Concrete Placing

Records of the details of every pour of concrete placed in the works shall be kept by the Contractor in a form agreed by the Engineer. These records shall include class of concrete, location of pour, date and duration of pour, ambient temperature and concrete temperature at time of placing and all relevant meteorological information such as rain, wind etc., moisture contents of the aggregates, details of mixes batch numbers, cement batch number,results of all tests undertaken, part of the structure and place where test cube samples are taken from.

The Contractor shall supply to the Engineer four copies of these records each week covering work carried out the preceding week. In addition, he shall supply to the Engineer monthly histograms of all 28 day cubes strength results together with cumulative and monthly standard deviations, Coefficient of Variation, and any other information which the Engineer may require concerning the concrete placed in the works.

C.11 Underwater Concreting

Concrete is often required to be placed *underwater or in a trench filled with the bentonite slurry*. In such cases, use of bottom dump bucket or tremie pipe is made use of. In the bottom dump bucket concrete is taken through the water in a water-tight box or bucket and on reaching the final place of deposition the bottom is made to open by some mechanism and the whole concrete is dumped slowly. This method will not give a satisfactory result as certain amount of washing away of cement is bound to occur. In case of Well bottom plugging, the same water level inside and outside the well shall be maintained till minimum 24hr of concreting.

C.11.1 Tremie Method

Underwater concreting using tremie method is convenient for pouring large amount of high flowable concrete. Tremie method is the most acceptable method of concreting under water.The concrete is moved to the hopper by either pumping, belt conveyer or skips.

Figure 3.1 Tremie Concreting Method

In this method ,a tremie pipe shall be inserted in the water up to the point where concrete is going to be placed. Generally the diameter of a tremie pipe varies from 20 cm to 30 cm. Depending upon the depth of concreting under water we can add more tremie pipe by coupling it with one another.

Before inserting the tremie pipe into the water, the bottom end of the tremie pipe must be closed with a plug or thick polythene sheet or other suitable material.

After tremie pipe reaches at the desired depth, a funnel is fitted to the top end of the tremie pipe, to facilitate pouring of concrete.

Then concrete having a very high slump of about 150 mm to 200 mm is poured into the funnel, until the whole length of tremie pipe is filled up with concrete.

Then the tremie pipe is lifted up and given a slight jerk by a winch & pulley arrangement. Due to application of jerk and weight of the concrete inside the pipe, the bottom plug fall and the concrete gets discharged.

At this stage, **make sure that the end of the tremie pipe remains inside the concrete, because this will prevent entering of water into the pipe from the bottom.**

When all of the concrete inside the pipe gets discharged, the tremie pipe is again completely filled with concrete and the process is repeated. This process of filling and discharging of concreting is repeated, without any interruption, until the concrete level comes above the water table.

Notes

- Pumping of water should not be allowed while concreting, because it may suck cement particles from the concrete.
- No compaction is required for under water concreting, as concrete gets compacted by the hydrostatic pressure of water.

Tremie pipe, which upper end connected to a hopper and lower end continuously submerged in fresh concrete, shall be used to place concrete at the exact location from a hopper at the surface. The reason to immerse the tremie pipe lower end is to prevent intermixing of both concrete and water. Tremie pipe typical arrangement is shown in Figure 3.2a.

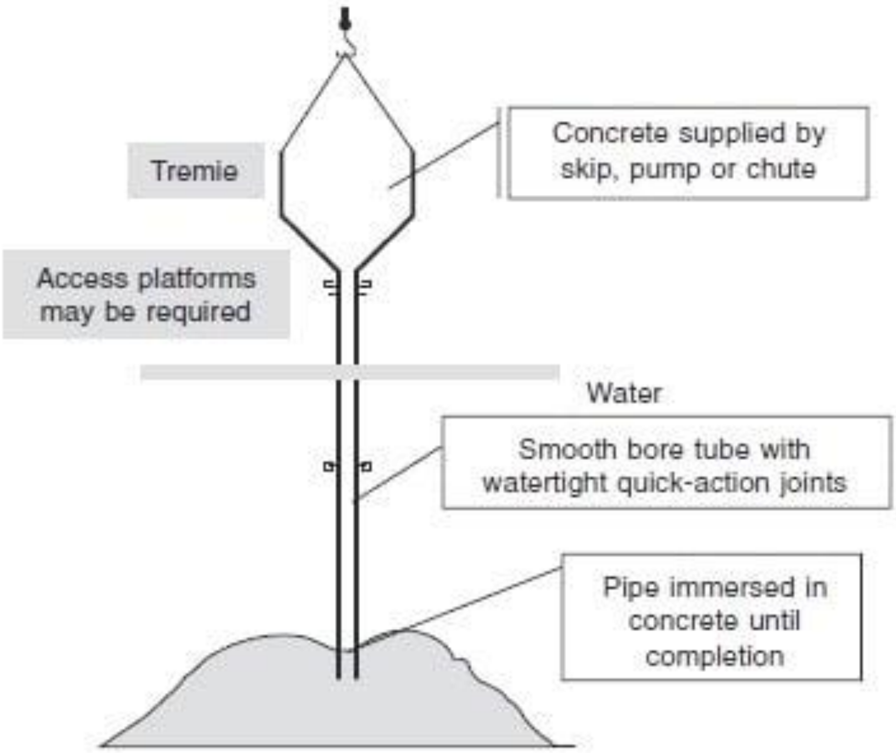

Figure 3.2a Typical Arrangement of Tremie Method of Underwater Concreting

There number of factors that should be considered during Tremie pipe technique of underwater concreting:

Tremie Equipment

The tremie pipe might be configured in three different ways such as constant length that is raised during concreting, pipe with different sections which dismantled during concreting and telescope pipe.

An aluminum alloy pipe can adversely affect the concrete due to chemical reactions between them therefore it should be avoided. The pipe should have an adequate diameter to prevent blockage because of aggregate size.

The usual diameter is between 200- 300 mm and occasionally 150 mm and 450 mm could be used but aggregate size should be considered for example 19 mm and 40 mm aggregate size is lower limit for 150 mm 200 mm pipe diameter respectively.

Tremie seal

To avoid intermixing water and concrete in the pipe, a wooden plug of plat is used to seal the end of the pipe. This prevents entering water in to the pipe and keeps it dry.

After the pipe reach the intended position the concrete is poured and break the seal. Then concrete flow out of the pipe and creating a seal by accumulating around the lower end of the pipe

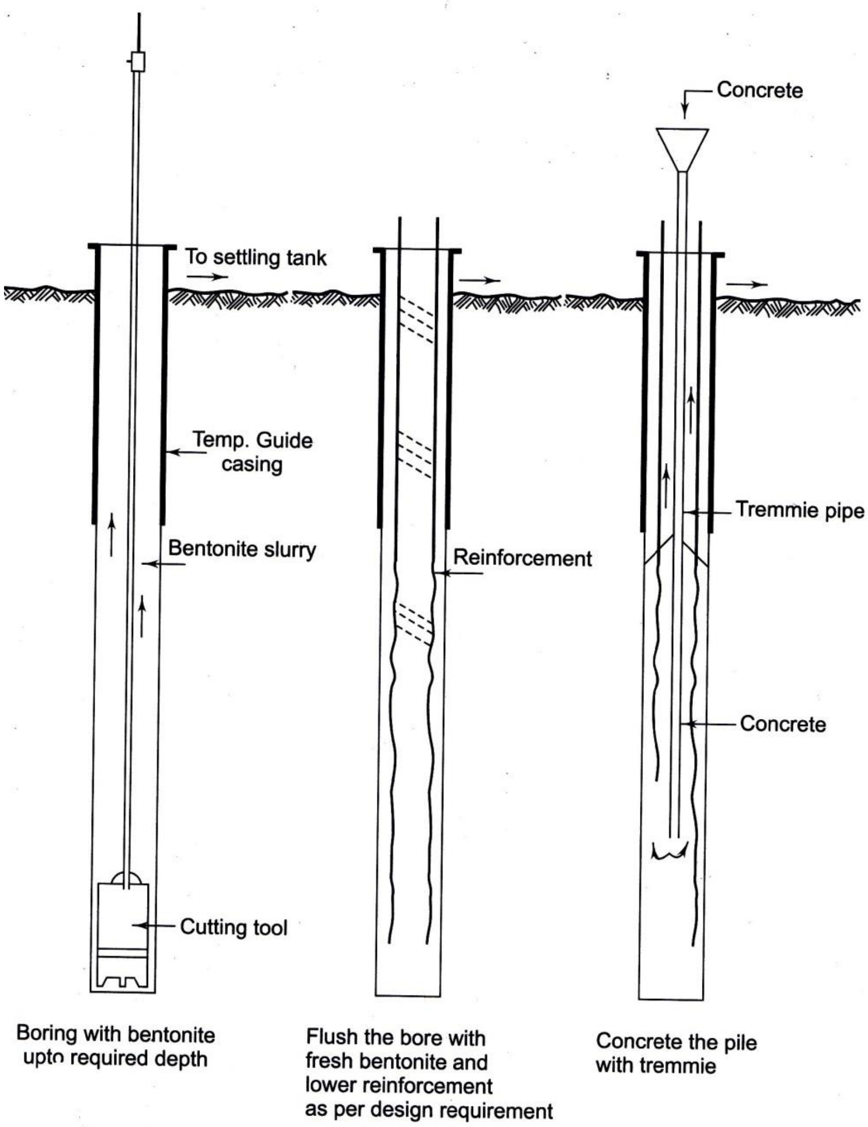

Figure 3.b Schematic drawing of concreting in Bored Pile

Placing the concrete

As soon as concreting began the pipe mouth should be submerged up to 1- 1.5 m into fresh concrete to prevent water entering the pipe. The concrete flow rate is controlled by lowering and raising the pipe and either decrease or increase in concrete discharge indicates the loss of the seal, therefore flow of concrete should be continuous and carefully monitored.

Flow pattern

Two types of flow pattern are recognized namely, layered and bulging. The bulging flow is desired because it displaced the concrete uniformly which leads to lesser laitance deformation and flatter slopes.

C.11.2 Pumping Technique

Underwater concreting using pumping technique is a developed version of Tremie pipe and it is quicker method for concreting in areas that is difficult to access such as under piers.

Pumping provide several advantages that Tremie pipe is lacking for example, pouring concrete from mixer to formworks directly, solve blockages in the pipe because concreting is through pumping instead of using gravitational force, and risk of segregation is decreased. Figure 3.3 show typical pipeline configuration.

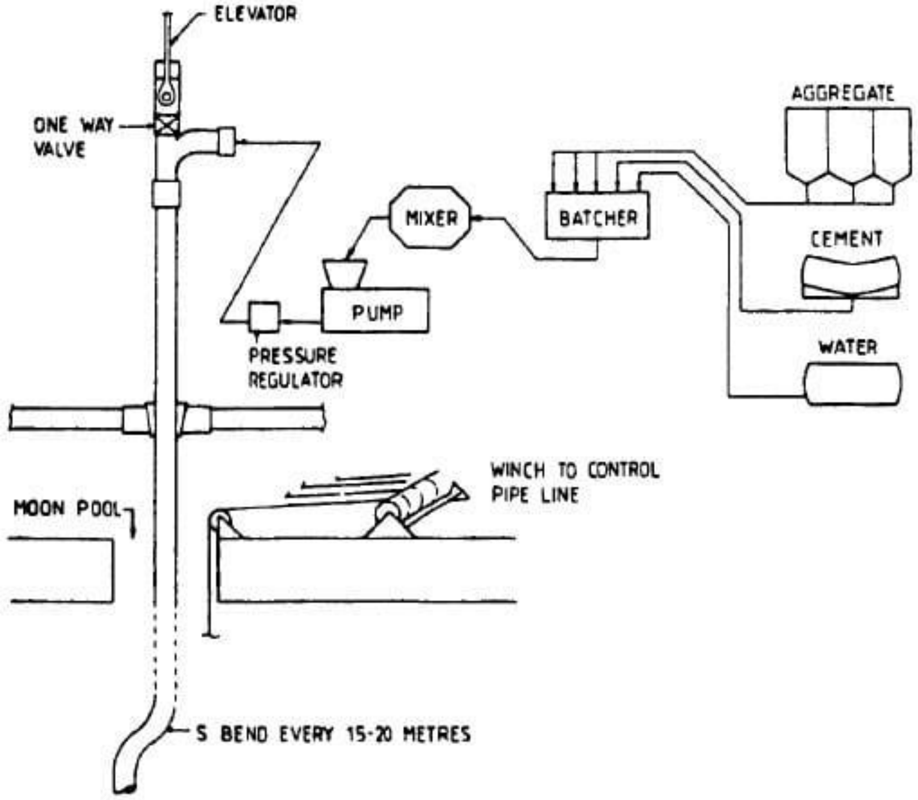

Figure 3.3 Typical Configuration of Underwater Concreting Pump Line

C3.11.3 Skips Method

The equipment that is used for conveying concrete is a bucket with double door opening at the bottom and overlapping canvas flaps which is fitted at the top to prevent concrete washing. The skip is lowered down through water slowly as soon as it filled with concrete and when it reaches the location the doors are opened either automatically or manually.

The Skip technique of underwater concreting is suitable for cases where a large mass of concrete is required for stabilizing foundations and small amount of concrete is needed for different locations. Shows opened and closed skips.

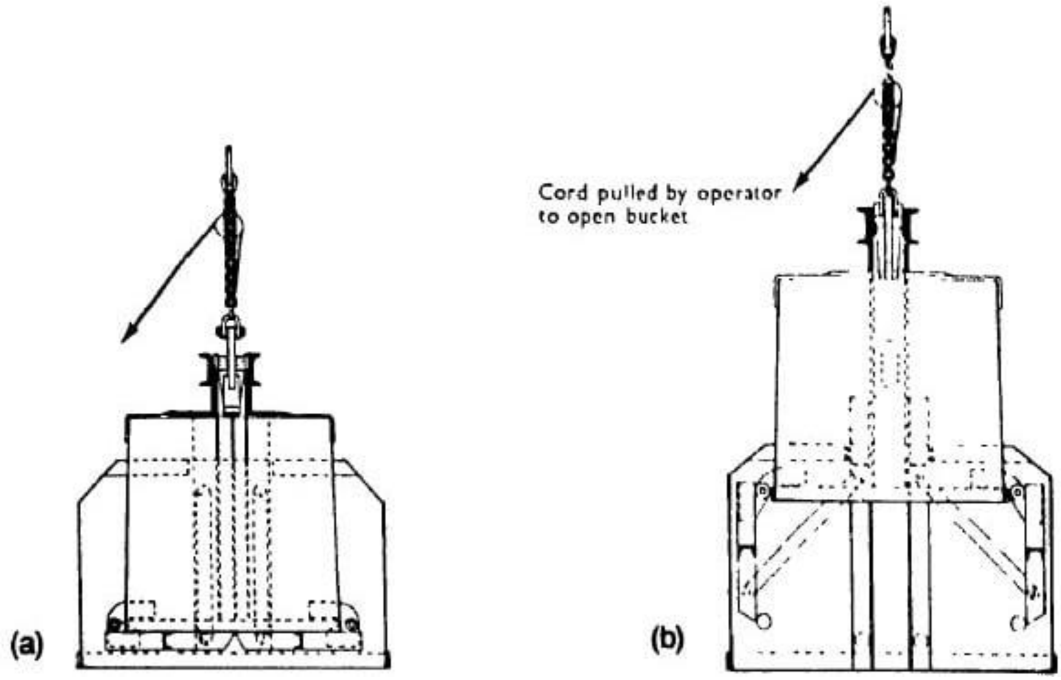

Figure 3.4 Skips for Underwater Concreting (a) Closed and (b) Opened

Underwater Concreting using Preplaced Aggregate Concrete & Bagged Concrete Method should be avoided.

C3.12. Concrete Quality Control

Random sampling and lot by lot of acceptance inspection shall be made for the 28 days' cube strength of concrete. Concrete under acceptance shall be notionally divided into lots for the purpose of sampling, before commencement of work. The basis of delimitation of lots shall be as follows;

i. No individual lot shall more than 30 cu.m. in volume
ii. Different grades of mixes of concrete shall be divided into separate lots
iii. Concrete of a lot shall be used in the same identifiable component of the Bridge/ structure

C3.12.1 Sampling and testing

Concrete for making 3 test cubes shall be taken from a batch of concrete at point of delivery into construction, according to procedure laid down in IS: 1199.

A random sampling procedure to ensure that each of the concrete batches forming the lot under acceptance inspection has equal chance of being chosen for taking cubes 150 mm cubes shall be made, cured and tested at the age of 28 days for compressive strength in Table 3.1. The 28-day test strength result for each cube shall form an item of the sample. Test at other age also shall also be performed, if specified.

Where automated batching plant/ Ready Mixed Concrete Plant is located away from the place of use and the time gap between production and placement is more than initial setting time or where any ingredients are added subsequent to mixing, separate set of samples shall be collected and tested at batching plant and at location of placement. The results shall be compared and used to make suitable adjustment at batching plants so that properties of concrete at placement are as per the requirements.

C3.12.2 Test specimen and sample strength:

Three test specimens shall be made from each sample for testing at 28 days. Additional cubes maybe required for various purposes such as to determine the strength of concrete at 7 days or for any other purpose.

The minimum frequency of sampling of concrete of each grade shall be in accordance with Table 3.4.

Table 3.4 Frequency of Sampling

Quantity of concrete in work (m^3)	No. of samples
1-5	1
6.1-15	2
15.1-30	3
31.1-50	4
51- and more quantity of work	4 plus one additional for each 50 m^3 or part of it.

C3.12.3 Acceptance criteria

The concrete shall be taken as having the specified compressive strength as per Table 3.1

"In case of a dispute about the strength of concrete in a particular area of the cast concrete, three 50 mm dia. and 100 mm. long Standard concrete cores shall be drilled out from such an individual area and tested for their crushing compressive strength. These values shall then be rectified for concrete age and how the cores were cut, and the corresponding equivalent "cube" strengths worked out for each core. If their average exceeds 85% of required 28 days works cube strength and none falls below 75% of the required 28 days works cube strength, then concrete in such disputed area may be accepted – but of course subject to contractual conditions for poor work.
Where minimum density of hardened concrete is specified (Generally 24KN/m^3), the mean of any four consecutive non – overlapping samples shall not be less than the specified value and any individual sample result shall not be less than 97.5 per cent of the specified value.

C3.13. Other

CAUTION AGAINST "PLASTIC-SHRINKAGE" CRACKING of Concrete AND USING EXCESSIVE DOSAGES OF ADDITIVES like 'RETARDER' and 'SUPER-PLASTICISER'

a) Plastic Shrinkage cracks develop prior to initial setting of concrete and can appear more prominently in slabs. If the rate of surface evaporation from the freshly laid concrete is faster than the rate of upward bleeding through it, the concrete surface tends to dry up, hence shrink, causing cracks in plastic concrete due to tension from this shrinking under such condition. These cracks travel downwards from the surface and their propagation is locked only upon 'initial setting' of concrete.
b) The longer the initial setting time, deeper will these cracks penetrate. Should they travel down to a significant depth of slab, then the slab can become a bunch of isolated concrete blocks separated by these cracks, and hence not be structurally monolithic with the rest of the Deck-section. Such deep-penetrating crack distress, in all probability, generally is not repairable by Epoxy filling of these cracks. The result may be a major Damage, requiring major rehabilitation.
c) Hence minimum doses of Retarders and Super-Plasticizers shall be used so as to keep the initial setting time to just the required minimum to allow the required 'workability' of concrete.
d) These cracks can be of random pattern (alligator-skin pattern) and/or may be somewhat parallel to each other and nearly perpendicular to the direction of wind that prevailed at the time of casting. Hence the field staff must look for these cracks before the concrete has initially set and , should these cracks occur, the plastic concrete should be quickly lightly 're-trowelled' on its surface (not re-vibrated) to close these cracks in time.
e) Reducing the ambient Temperature and increasing the ambient Relative Humidity (by Fog-spraying), lowering the Temperature of Concrete to less than 32ºC (by cooling the Aggregates and the mix-water), and reducing the Dosage of Retarder and Super-Plasticizer, will help in controlling the endemically dangerous Plastic Shrinkage Cracking.
f) Concrete slabs which are correctly re-trowelled should not exhibit Plastic Shrinkage cracks because the action of floating and trowelling is a form of recompaction that tends to close them as fast as they form. (This trowelling can, however, aggravate sedimentation of solids in the mix and cause Plastic Settlement cracks – see ahead.)

g) Although the Plastic Shrinkage cracks can be wide at their start (even up to 2 mm), the width rapidly diminishes with depth. Nevertheless, in severe cases they may pass through the full depth of a slab, in contrast with most types of Plastic Settlement cracks.
If not noticed in the soffit of not-easily-accessible-slab-soffits, thorough wetting at the top of the slab may show them in case of full depth penetration. Taking cores can reveal them precisely.

h) Plastic Shrinkage cracks rarely reach the free ends of the slab (e.g. the edges of a slab) because these edges are free to move under plastic shrinkage. This is a very important way of differentiating them from long-term drying shrinkage cracks if the time of formation is unknown. However, Plastic Shrinkage cracks will form up to the ends of a slab which has been cast against a previous pour, especially if there is continuity of steel, because this acts as restraint.

i) The factors that determine rate of surface evaporation are: the temperature of the concrete, the air temperature, relative humidity, and wind velocity of the air adjacent to the concrete. The evaporation increases as the humidity decreases, as the wind velocity increases, as the air temperature decreases, and as the concrete temperature increases. Of particular interest is the fact that rapid evaporation is at least as big a problem in cold weather as in hot weather! Even when the relative humidity be 100 per cent in cold weather, there will be a large amount of evaporation if the concrete is warm! Of all the factors listed above, only the concrete temperature is easily controllable. There is a definite advantage to cool the concrete! It shall be placed as cool as practical in warm weather and should not be overheated in cold weather. If the concrete temperature is reduced to about 27ºC to 15ºC, much of the evaporation can be eliminated!

j) In hot weather, sometimes concreting during 4 p.m. on the previous day up to 12 noon on the next day may be resorted to for preventing formation of Plastic cracks and obtaining better quality concrete. But this will be effective only if it gives significantly lower concrete temperatures and lower wind velocity. The reduction of air temperature BUT not that of concrete (even with the increase in relative humidity) will not significantly reduce the Plastic Shrinkage cracking.

k) If it is not possible to eliminate the risk of Plastic Shrinkage cracks even by improved timely curing, then changes to the concrete mix must be considered. First, check that the concrete does not contain an admixture with high retarding effects. If it does, try to reduce it or replace it with the one that does not retard so much (rather than counter it by adding a compensating accelerator!). Second, consider the use of air entrainment. Air-entrained concrete exhibits less Plastic Shrinkage cracks than plain concrete. At first sight this might seem illogical because as air entrainment reduces the rate of bleeding it should increase the risk of Plastic Shrinkage cracks occurring at a given rate of evaporation. However, most commercially available air-entraining agents are ‘detergents’ and therefore reduce the surface tension caused by drying, and consequently reduce the shrinkage cracking.

l) The prevention and timely repair of Plastic Shrinkage cracks in slabs is particularly critical. This is because the cracks are wide at the top and can rapidly take in pollutants which may cause subsequent spalling and prevent the subsequent satisfactory application of sealing materials. Clearly wide cracks in slabs are not likely to be self-healing at the top and are likely to spall and allow ingress of pollutants.

CAUTION AGAINST POSSIBLE DAMAGE DUE TO "PLASTIC SETTLEMENT" CRACKING OF CONCRETE

a) Plastic Settlement cracks occur in not-yet-initially-set concrete when there is a relatively high amount of bleeding through it and some form of obstruction to the downward sedimentation of its solids (e.g. the reinforcement bars). These obstructions ‘break the back of the settling concrete’ over them as its solids fall downwards around them, fomenting formation of hollows under their ‘belly’. Thus Cracks show directly over formwork-tie-bolts and over reinforcement near the top of the plastic concrete, reflecting their pattern. Such Cracks can also appear in narrow columns and walls where the said sedimentation is prevented by the resulting arching of the concrete due to downward passage for sedimentation and there may be further aggravation by the presence of horizontal bars.

b) Plastic Settlement Cracks can be prevented by reducing the bleeding and hence the sedimentation, and by reducing the obstructions to sedimentation.

c) Admixtures such as plasticizers reduce water demand and thus are the most effective way of reducing bleeding and sedimentation and hence the plastic settlement cracks. These can also be eliminated by light re-vibration (not re-trowelling) of the not-yet-initially-set concrete if they have formed, thus also filling back the under–belly hollows.

d) This light re-vibration shall not be applied too soon otherwise a second phase of bleeding can still cause Plastic Settlement cracks. The correct time can easily be determined by simple site trials: it will be the last time that a vibrating poker can be inserted into the concrete and removed without leaving a significant trace. Re-vibration is often the only way to eliminate plastic settlement cracks, particularly in deep sections. Trowelling the surface can actually aggravate these cracks as the pressure may only cause further settlement of solids!

ii. BEWARE OF CRACKS DUE TO "PLASTIC–SHRINKAGE" and "PLASTIC SETTLEMENT" IN CONCRETE WHILE IT IS STILL PLASTIC AND HAS NOT YET ATTAINED "INITIAL SET"

a) Plastic cracks by their very nature pass through the cement matrix and around aggregate particles; therefore they are very rugged and capable of transferring shear, providing there is sufficient reinforcement to maintain aggregate interlock. Consequently full structural repairs (using epoxy formulation) may not be necessary, though preferable….BUT only if the crack penetration is minor BECAUSE otherwise if deep penetration damage is done, EPOXYING WILL NOT restore full monolythicity (…..in which case the Deck-slab may have to be demolished, requiring major and very costly rehabilitational exercise). HENCE BEWARE OF PLASTIC CRACKING!!

b) If cracks follow the pattern of the top reinforcement it may be difficult at first to determine whether they are due to Plastic Shrinkage or Plastic Settlement. If it can be shown that the cracks 'pass through the slab' and follow the pattern of the steel, then they are almost certainly Plastic Shrinkage cracks that have been orientated by the steel!

c) Plastic cracks often form in the top face of sections e.g., Plastic Shrinkage cracks in slabs, and/or Plastic Settlement cracks on top of deep beams and walls. Thus they can be accessible, and this coupled with the fact that they form so early in the life of concrete, means that they may widen as thermal contraction and drying shrinkage take place. Consequently it may not be wise to fill plastic cracks with 'rigid' epoxy materials until it is certain that the long-term effects have subsided.

d) Plastic Settlement cracks over steel must be immediately and efficiently 'sealed' if the concrete is in an exposed state (to eliminate the risk of corrosion of the steel). Reduced bond strengths due to under-belly voids thus formed under steel bars are dangerous.