Some steps towards producing durable structures in cement concrete at project sites

Kartik Chandra Ta

Durability of cement concrete means that the given concrete will continue to perform its intended functions i.e maintain its required strength and serviceability during the expected service life without showing any sign of deterioration/ distress. In simple traditional structures expected service life may be 25 to 50 years while in case of very important structures and those of national importance this may extend to 100 years or even more. There is no such thing as inherently durable concrete as due to change of usage deterioration may be faster and also a concrete durable under one set of conditions of exposure may not be durable under another set of conditions.

Causes for deterioration may be external to the concrete structure generally mechanical in action or may be internal within the concrete which are chemical actions that include alkali-silica reaction or alkali-carbonate reaction in some parts of the world. Again, deterioration of concrete is rarely due to a single isolated cause. Being a patient material, it can perform satisfactorily despite some adverse conditions but with an additional adverse factor damage may take place.

It must not be assumed that required durability would be ensured by only achieving desired strength of concrete. Again we should not be pre-occupied with durability to the exclusion of strength. The most important ingredient for any durable concrete is however the human one [1].

Various reasons for deterioration as well as preventive measures required at project sites to produce durable cement concrete have been discussed in this paper.

A. PRINCIPAL CAUSES OF EARLY DETERIORATION OF CONCRETE STRUCTURES DURING SERVICE LIFE

Field experience shows that, in order of decreasing importance, principal causes for deterioration of concrete structures are corrosion of reinforcing steel, exposure to cycles of freezing and thawing, alkali-silica reaction and sulphate attack. With each of these four causes of concrete deterioration, permeability and the presence of water are implicated in the mechanisms of expansion and cracking. Properly constituted, placed, consolidated and cured concrete is essentially water-tight and should therefore have a long service life under most conditions. However, as a result of environmental exposure, cracks as well as micro cracks occur and propagate. When they interconnect, a concrete structure loses its water tightness and becomes vulnerable to one or more processes of deterioration. [2]

a. Chemical action

Deterioration of concrete can be external to the concrete structure or there may be internal causes within the concrete itself. Actions of these may be chemical or physical. Internal causes include alkali-silica reaction or alkali-carbonate reactions, both of which are chemical actions. If the concrete is dry and no water from outside can enter into the interior of concrete then no further alkali-aggregate reaction will take place. The more the penetrability of concrete the more severe would be the action of aggressive salts to cause deterioration.

The most common chemical forms of attack arise from outside of concrete being action of aggressive ions, such as sulphates as well as many natural or industrial liquids and gases. In addition, chlorides present in concrete mix through its ingredients and carbon dioxide in the form of mild carbonic acid are conducive to the corrosion of reinforcement bars. Corrosion also requires the ingress of oxygen at the cathode [3]. Both of the above are linked to ingress of salt bearing solutions into the concrete by flow, diffusion and sorption.

b. Physical action

Physical action includes repeated cycles of freezing and thawing and the associated action of de-icing salts and also temperature effects which can be due to high temperature of concrete at the time of placing or high temperature differential between different parts of a thick concrete member. A large differential between the coefficient of thermal expansion of the aggregate and of the hardened cement paste can be destructive if there are numerous cycles of temperature variation [3].

Deterioration of concrete can also be caused by salt weathering at the surface of the concrete by cracking due to excessive thermal gradients and excessive plastic or drying shrinkage and autogenous shrinkage. Resulting cracks make it easier for harmful agents in solution to penetrate into the concrete.

c. Mechanical action

Mechanical damage is caused by impact, abrasion, erosion or cavitation. Impact may be caused by repeated fall of an object or single impact of a large mass at a high velocity. Abrasion is common in hydraulic structures by action of abrasive materials carried by water. Another cause of damage to concrete in flowing water is cavitation. Erosion is an important type of wear which may occur in concrete in contact with water.

(Mechanical damage has not been dealt in detail in this Paper)

B. SOME MEASURES RECOMMENDED TO ENSURE DURABILITY OF CONCRETE STRUCTURES

Durability of concrete largely depends on the ease with which fluids both liquids and gases can enter into and move through the concrete which is commonly referred to as permeability of concrete but should be termed penetrability as permeability strictly speaking refers to flow through a porous medium[1]. Surface layer of concrete plays an important role in resisting ingress of aggressive ions.

In order to produce durable high performance concrete with low permeability the following are some of the requirements:

i. Proper design not only from point of view of strength but also with respect to exposure to local conditions and microclimate.

ii. High cementitious materials content (between 450 and 550 kg/cum)

iii. Low water/binder ratio (preferably below 0.35) to produce dense structure of hydrated cement paste with a discontinuous capillary pore system using chemical admixture as needed.

iv. Addition of flyash and/ or GGBS and silica fume. Silica fume reduces permeability of the transition zone around the aggregate particles as well as of the bulk cement paste. Influence of silica fume on permeability is much greater than on compressive strength.

v. Proper execution with a high level of supervision, quality control and quality assurance

vi. Systematic maintenance

The above are detailed in following paragraphs:

a. Adequate supervision

Good design and materials alone will not assure durable concrete nor good concrete coming out of the mixer. Good quality control and workmanship are absolutely essential to production of durable concrete. A concrete structure is a product which cannot be verified only by inspection and limited testing in its finished state, deficiencies may become apparent only after the passage of time. Hence enormous importance of adequate supervision so as to ensure that the execution of construction complies with the specifications and desired quality is achieved while lack of supervision is likely to result in poor quality of construction due to human nature or worse still due to ignorance, idleness or greed of some people involved [3].

It is essential that

i. Persons engaged in batch mixing, pumping, placing at location of concrete, vibration of concrete and finishing are properly trained in these skilled jobs for success.

ii. Staff members at site are provided training in Quality Assurance measures.

iii. Field Quality Plan (FQP) is prepared along with Inspection and Test Plan (ITP) as per contract requirements, got approved by Client's Engineer and the same are strictly followed till completion of the project.

iv. Detailed work methodology is prepared for each major item of work well in advance, got approved by Client's Engineer and rigorously followed without deviation.

Figure 1 shows fair face concrete structure of a 55 m high Airport Control Tower and Figure 2 shows concrete surface of one Urea Prilling Tower, 99m high along with staircase and lift shaft in slipform construction, all without any rendering.)

b. Use of proper ingredients

i. Cement

In concrete cement normally used is of grades 33,43 and 53 and Type Ordinary Portland Cement (OPC), Portland Pozzolana Cement (PPC), Sulphate Resisting Cement (SRC), Portland Slag Cement(PSC) based on special requirements at site conditions.

Figure 1. Control tower at Delhi Airport 55 m high (Year 1993)

To attract customers with high strength of concrete at early age with option of early stripping of formwork particularly in precast concrete work some cement manufacturers have increased C_3S in OPC from usual 42 p.c to around 58 p.c and correspondingly reducing C_2S content from 28 p.c to 12-13 p.c. In such cases it must be checked through cement mortar test at site laboratory that in 28 days strength of concrete does not fail to satisfy the codal requirements for the particular grade of concrete. In case of doubt in cement quality received at site sample shall be sent for chemical analysis in external approved laboratory. On the basis of early strength gain if any cement is used and stripping of formwork is done early then curing also shall be started immediately after removal of forms.

Storage of cement shall be done as per codal provisions and principle of first come first use shall be adopted.

Figure 2. Urea prilling tower built using slipform at a fertiliser plant in U.P

ii. Mineral admixtures

Normally these admixtures are used to improve various properties of concrete like impermeability, strength and durability of concrete etc.

Flyash, Ground Granulated Blast Furnace Slag(GGBS) and Metakaoline are commonly used mineral admixtures which may be mixed with OPC at site batching plant to improve different properties of concrete. In production of PPC and PSC, cement manufacturers use flyash and blast furnace slag respectively upto the p.c specified in relevant codes.

Microsilica or Condensed Silica Fume (CSF) which is almost 100 times finer than cement particles can be used in quantity between 5 and 20 p.c by wt of cementitious materials in any type of cement. By such use the concrete mix is strongly cohesive and there is very little bleeding. The reduced bleeding can lead to plastic shrinkage cracking under drying conditions unless preventive measures are taken. On the other hand, voids caused by trapped bleed water are absent [1].

iii. Coarse aggregates

Maximum size is normally 20 mm, while for PCC and thick rafts sometimes 40mm size of aggregate is used. In very thin members maximum size may be reduced to 10-12 mm. Grading is to be checked as per IS 383 [4] and tests for acceptance of coarse aggregates are to be conducted as per relevant IS codes.

Additional tests to be conducted on crushed stone aggregates brought to site initially and at periodic intervals/change of source shall include chloride and sulphate content of aggregates.

iv. Fine aggregates

Naturally occurring river sand and pit sand, crusher sand/ manufactured sand processed from stone aggregates are normally used as fine aggregates in concrete. Grading of sand and deleterious materials content in sand are to be checked to satisfy requirements of IS 383-latest revision [4]. It has been proved through several researches in reputed laboratories in India that properties of crusher sand/manufactured sand are superior to river/pit sand in many respects.

v. Water

Potable water is normally satisfactory for mixing and curing of concrete. pH value shall not be less than 6. Permissible limits of solids in water shall not exceed the values specified in IS 456-latest amendments [5].

For a new source of water before its bulk use in concrete production compressive strength of concrete shall be tested for 3 and 7 days with sample of such water.

vi. Chemical admixtures

Superplasticizers help in lowering water/binder ratio which contributes towards enhancement of durability. Different types of Chemical Admixtures normally in use are Accelerating Admixture, Retarding admixture, Air Entraining Admixture, Superplasticizing Admixture, Retarding Superplasticizing Admixture, High Range Water Reducer, Corrosion Inhibitor Admixture, Viscosity Modifier, Quick setting Admixture and Integral Waterproofing Admixture depending on requirement and particular purpose each admixture serves. Tests for chemical admixtures shall be conducted in approved external laboratory before source approval to satisfy requirements of IS 9103-latest revision [6].

In selection of Chemical Admixtures the following need to be considered:

1. Compatibility between the particular type, brand and clinker source of cement and the particular chemical admixture proposed to be used in any project must be checked by laboratory trials prior to taking a decision on their use in design of a concrete mix. A particular admixture compatible with one brand of cement from a plant of one manufacturer may not be compatible with same brand of cement from a plant at another location of the same manufacturer.
2. Admixture chemistry being complex and dissimilar and also since interactions between admixtures cannot be easily predicted and understood, it is not advisable to use multiple admixtures in a particular concrete. If however, special properties are needed and for that multiple admixtures are to be used, a thorough compatibility evaluation shall be made before such use.
3. In case time taken for transport of concrete in transit mixer from a concrete batching plant located far away from project site gets extended beyond slump retention time considered in mix design, due to being detained on road for traffic congestion on way and/or temporary breakdown of the mixer during transit, then as per international practice re-dosing of chemical admixture can be done in transit mixer concrete and mixed thoroughly before discharging. However prior trial should be made with extra dose of admixture @ 5 p.c, 10 p.c, 15 p.c and 20 p.c over the design quantity of admixture for revised retention period and relevant strength of concrete.

vii. Concrete mix design, Quality Control, Technical and Quality Audits

Procedure for mix design is given in IS 10262, latest revision [7]. The following issues should be given due consideration in mix design:

1. Trials should be made with more than one brand of cement, chemical admixture and source of mineral admixture available locally and mix proportions kept ready so that in case supply from any of the brands/ sources of above materials is stopped by supplier due to any reason, immediate switchover to another mix can be made fast without hampering progress of work.
2. In site laboratory complete facilities should be available to maintain required room temperature, all testing equipment in working order as required as per contract shall be supplied and those would have latest calibration certificates.
3. Qualified and trained Quality Control Engineers and sufficient trained Field Assistants are essential for running a site laboratory smoothly along with proper documentation. All tests as specified in Field Quality Plan/ Inspection and Test Plan for ingredient materials, green concrete and set concrete, inspection at factory premises and finished products, where required, would be conducted by competent QC staff without hampering progress of work.
4. In order to get best results from mix design in laboratory, such trials should simulate as far as practicable actual conditions expected at site batching plant with respect to ambient temperature, use of vibrator, moisture content of aggregates, use of ice/ice flakes or any other cooling methods to be adopted, cement, aggregates, mineral and chemical admixtures to be actually used.
5. Technical Audit - Drawings issued for construction shall include all details and informations without any ambiguity. The designer should be involved at construction stage to satisfy himself by paying visits to project site in agreement with client that work is being executed as per design and drawings.

   In case of major and very important projects it is suggested to engage Proof Consultant to check design and drawings prepared by the project Consultant.
6. Quality Audits - Apart from Contractor's periodic internal audits, in major projects Client's Audit and Third Party Audit should be organised in order to assure uniform quality of high standard required for durable structures.

c. Reinforcement bars

1. Type Fe 250, Fe 415, Fe 450, Fe 500, Fe550 grade are manufactured in India along with Fe 450 D, Fe 500D and Fe 550D which are meant for earthquake resistant structures, all satisfying requirements of IS 1786 [8]. Based on manufacturing processes plain MS rounds, High yield strength deformed bars (HYSD), Thermo-mechanically treated bars (TMT) are commonly used. Corrosion resistant steel (CRS) and High resistance against corrosion (HRC) bars are also manufactured by some parties in India. However, their claim against corrosion resistance should be thoroughly investigated before their use for specific purpose.
2. Coating over bars normally used for projects in coastal areas in India is with fusion bonded epoxy while in some projects CECRI recommended coating has been used for corrosion protection of bars. Use of galvanised coating on bars and of stainless steel bars is very limited so far mainly due to high costs involved.

   Corrosion inhibitor admixture may be used in cast-in-situ pile concrete in foundations for protection of reinforcement bars from corrosion.
3. The Author has past experience of poor quality of TMT bars from both reputed and not-so-reputed manufacturers in India in respect to the following:
   i. During unloading of bundles of bars from a lot received in a few trucks from a reputed manufacturer in India some bars had broken and the entire lot with doubtful quality had to be rejected and returned.
   ii. Out of 12 m full length TMT bars received from one manufacturer during bending the bars had broken at 1 m from each end as proper quenching required in TMT process could not be done due to quenching bath in manufacturer's yard being less than 12 m.
   iii. At a high rise private building site in one of the metropolitan cities in India out of 45 Nos samples of bars of different dia purchased from local market when tested in an external approved laboratory 11 Nos failed to satisfy requirements of Yield strength or Ultimate Tensile strength or Elongation criteria as per IS 1786[8]- latest amendment.
4. Reference is also drawn to publication based on research on quality of reinforcement steel by Torsteel Research Foundation, Bangalore[9] in which it is observed that 'statistical analysis showed that

about 8 p.c of the tested re-bars come under the category of defective and sub-standard re-bars and about 1/3 of this 8 p.c were substandard re-bars. This is considered to be very high p.c in view of the structural risks encountered in constructions with such re-bars. Even about 0.5 p.c failure is considered to be a very high and risky figure since every bar in a structure is directly responsible for the safety and /or durability of the structure'.

With general quality of steel reinforcements available in India as stated above, **it is advised** that reinforcements should be purchased only from reputed manufacturers with proper testing laboratory and quality control facilities in the production unit. Apart from Manufacturer's Test Certificate (MTC) from each lot received from the supplier at certain intervals and in cases of doubt random samples of bars of different dia should be mandatorily sent for test of mechanical properties in a testing laboratory in a Govt Engg College or Research Institute or private laboratory with NABL accreditation for such testing. Occasionally chemical analysis on bar samples of each dia also should be done particularly after any sample fails to satisfy requirements of mechanical properties and/or there are any doubts from physical appearance of steel e.g. split ends, cut marks on surface or if during bending sample breaks etc.

5. Adequate cover to reinforcement bars (re-bars) - Adequate cover provided in thickness and quality using cover blocks of approved material is necessary for transfer of forces in steel reinforcements, to provide fire resistance to steel and an alkaline environment at surface of bars to prevent corrosion.

   If cover provided is inadequate often reflection cracks develop on horizontal finished surface of slabs/ footings or vertical columns/wall surfaces in same alignment of reinforcement bars below/behind which would severely affect durability of those structures.

   Cover zone should not be encroached by knots of binding/tying wire used for fixing of reinforcements in position as per Figure 3. It shows such encroachment as per wrong practice generally followed at project sites. Such knots should be provided inside i.e in core of concrete columns and walls while in slabs and rafts these should be located below top bars and above bottom bars. This practice should be enforced if required, on extra payment as several cases of failure have been reported in the past due to reinforcement corrosion starting from cover zone.

Figure 3. Reinforcements tied with knots placed in cover zone

d. Staging and formwork

i. Staging

Mild steel scaffolding pipes, support trestles built-up of steel sections and bars, aluminium built-up sections and other proprietary pipe supports normally used as staging material must be strong enough and properly designed with adequate factor of safety to carry dead load from structure and incidental live load during concreting.

Special care shall be taken when staging height, length and weight of unit to be cast in single operation are all of large magnitude as the risk factor from loss of life, wastage of materials, slippage in completion of work, resulting financial loss and loss of reputation due to collapse of such staging would be enormous.

Figure 4 taken after a thick subway slab under a National Highway collapsed during construction due to poor design of support system is attached.

Figure 4. Damaged wall pier after collapse of staging for a subway roof slab

ii. Formwork

Resin bonded plywood sheets attached to timber frames are commonly used apart from heavy duty metal formwork, proprietary timber beam plywood formwork, polypropylene and fibreglass formwork, steel formwork shutter panel with plywood, aluminium alloy formwork, plastic formwork, galvanised high ribbed formwork, inflatable rubber/ pneumatic rubber formwork on the basis of special requirements, cost etc.

Permeable formwork is now in use in some projects to improve quality of cover concrete for extended durability. In this formwork for vertical surfaces consists of a polypropylene fabric fixed to plywood backing which contains drain holes. Thus the formwork acts as a filter through which air and bleed water escape but the cement is, for the most part retained in body of the concrete although it is carried towards the formwork. In addition to reducing the formwork pressure, the permeable formwork lowers the water/cement ratio in the surface zone, upto a depth of 20mm. The effect of the greatly reduced water/cement ratio is to reduce surface absorption and water permeability of the outer zone of concrete which is often critical from durability standpoint. The surface produced by permeable formwork is free from bleed streaking and entrapped air pock-marks, thus enhancing the appearance of the exposed surfaces [1].

Design of support system for formwork of various sizes with different types of materials should be done for concrete pressure, rate of pouring etc on the basis of standard principles. For columns of length 10 m or more to be cast in single lift special care shall be taken in design including method of pouring concrete, compaction, stripping of formwork etc.

e. Concrete batching and mixing

i. Automatic weigh batchers of capacities as required in the project are to be used with provision of weighment of all ingredients including water. Calibration of load cells should be done at regular intervals depending on usage of the plant and limits of accuracy to be maintained as per stipulations of relevant code.

ii. Mixing of ingredients for production of concrete may be done using Tilting type or Non-tilting / Drum type or Pan type mixers. Each has its advantages and certain disadvantages. However, it is essential that sufficient interchange of materials between different parts of the chamber takes place, so that uniform concrete is produced. Time for mixing of concrete should normally be not less than 2 minutes per batch to achieve uniformity of mixing. In this regard batching plant manufacturer's quoted mixing time may be taken as a guide. Regular maintenance of the Batching plant components shall be ensured for best results

iii. In sequence to be followed in discharge of ingredients into the mixer it is suggested that where microsilica is used the same should be added next to addition of coarse aggregates and before addition of sand and other ingredients for the best results.

f. Transport of concrete

i. When concrete batching plant is located away from project site normally mix is transported by Transit Mixers (TM)of different capacities as per requirement. During hot weather wet wrapping outside the rotating drum should be done to minimise increase in temperature of concrete during transport.

ii. In pumped concrete the following should be kept in mind:

1. Not all concrete is pumpable and minor variation in concrete mix is sufficient to make an otherwise pumpable mix completely unpumpable. The sand grading is particularly important and variations in grading can rapidly cause unpumpability.

2. Pumping would be easier if a slow, steady rate of pumping is used because both the risk of mix disintegrating and the friction are decreased by slowing the rate of placing. For an efficient working the supply of concrete quantity, rate of pumping, capacity of placing and compacting gang should match and also sufficient spares for pumps and pipelines should be made available in stock at site store for fast replacement of defective/worn-out parts.

3. For lubrication of concrete pipeline cement sand mix slurry at the rate of about 0.25 cum per 100 m length of 150 mm dia pipe is recommended to be pumped before pumping concrete [1]. Alternatively chemical lubricants

not reactive to concrete may be used. Pipes should be thoroughly cleaned after use.

g. Placing and compaction of concrete

1. Concrete should be placed as close to its final position as possible and shall not be made to flow by vibrating it which may result in segregation and would show on the surface of finished work.

   Where concrete is transported by crane and bucket instead of making big heaps in small Nos it is preferred to empty concrete from bucket in large No of small heaps which is sufficient for the immediate area to be placed so that manual handling is minimised.

2. Maximum free fall of concrete should be limited to 1.5 m and in case of high columns to be cast in single lift flexible hose or circular steel chute is to be used in one or more pieces depending on height of columns to limit free fall height. In such cases vibrating nozzles with long shafts are to be used with aid of Form/ Shutter vibrators where sizes are big. Concrete mix would be specially designed to avoid segregation and to suit particular placing conditions.

3. Before start of concreting rubbish such as sawdust, shaving and binding wire pieces and any other foreign materials shall be removed by compressed air or water jet. Where forms are deep, temporary openings may be provided for inspection to be closed subsequently before concreting.

4. Formation of cold joint in concrete between layers/ adjoining panels in in-situ construction shall be prevented and to avoid such formation revibration with previously placed layer upto a depth of 10 cm or so when still green shall be ensured. Also rate of supply and placing of concrete shall be synchronised with mobilisation of batching plant of adequate capacity, No of transit mixers, hoisting arrangement, No of vibrators with spares and skilled workmen required for the purpose.

   Figure 5 shows cold joint formation in an inclined plain in a deep bridge girder.

5. At junction between old and new concrete before start of concreting the surface should be wetted with water followed by application of cement sand mortar of same proportion as in concrete. Alternatively, proprietary bonding agent from reputed manufacturer may be applied at junction between old and new surface prior to concreting following strictly the instructions in relevant literature of the product regarding time gap between application of bonding agent and concreting against applied surface.

h. Bleeding

Bleeding also known as water gain is a form of segregation in which some of the water in the mix tends to rise to the surface of freshly placed concrete. This is due to inability of the solid constituents of the mix to hold all of the mixing water when they settle downwards, water having the lowest specific gravity of all the constituents.

Initial bleeding proceeds at a constant rate but subsequently the rate decreases steadily which however continues until

Figure 5. Cold joint formation in a deep bridge girder

the cement paste has stiffened sufficiently to put an end to process of sedimentation. If bleeding water is remixed during finishing of top surface, a weak wearing surface, consisting of laitance will be formed. This can be avoided by delaying the finishing operations until the bleed water has evaporated and also by use of wooden floats and avoidance of overworking the surface. On the other hand if evaporation of water from concrete surface is faster than bleeding rate plastic shrinkage cracks will develop.

i. Finishing of concrete and prevention of cracks before final set

Attempt should be made by all Engineers at site to produce crack-free structures in view of serious adverse effect of such cracks due to subsequent ingress of harmful chemicals, moisture and gases prevalent in air and surrounding such structures which would lead to fast deterioration of such structures.

Bearing in mind that sunrays and surface wind are both dangerous in producing cracks on green concrete surface mainly due to evaporation loss, such cracks can be prevented by adopting one or more of the following measures :

1. Subsequent to finishing of concrete within next 1½ to 2 hours (depending on ambient temperature and/or intensity of surface wind) when surface of concrete has been just dry with no impression appearing when pressed by finger the surface of concrete has to be covered by plastic sheet or hessian cloth. Alternatively curing compound is to be spread where finished area per hour is quite large e.g. PQC in concrete roads to prevent loss of water from green concrete by evaporation during hydration stage.

   Sprinkle water on hessian cloth surface after sometime when final set of concrete is started i.e. when a person can stand on the concrete surface.

   Also to prevent washout of green concrete before or after compaction and finishing during rains enough covering material shall be mobilised for the purpose.

2. Finishing gang comprising mason / helper and at least one Engineer / Supervisor should be retained at site at least for 1½ to 2 hours after initial finishing of concrete surface to check development of any crack and arrange for covering of concrete surface even if finishing is completed at night. If any crack is developed during this period when concrete is still green final finishing on the concrete surface using steel trowel should be done to eliminate such cracks.

   Also if any excess bleeding water gets accumulated on top after initial finishing of concrete surface the same shall be soaked using sponge or hessian cloth and not allowed to evaporate on its own nor any dry cement be applied at this stage.

   When surface gets dry, finishing should be done for the second time. Figure 6 shows finished concrete surface with lot of bleeding water not removed properly.

3. It should be the duty of the Engineer / Supervisor attending concreting previous day or night to inspect the concrete surface for any visible cracks next morning particularly before curing is started. If after taking all precautions during final finishing still some fine cracks have developed such areas should be isolated creating barriers with cement / sand mortar normally used for ponding. Then dry cement powder should be pressed by hand on the fine cracks. Such isolated areas would be kept covered for 4 to 6 hours before water curing is started here while in rest of areas of concrete surface curing by ponding water or using wet hessian cloth/burlap should be started as per specification.

Figure 6. Finished concrete surface with bleeding water unattended

Figure 7(a) shows nozzles fixed and 7 (b) shows epoxy injection in progress on a roof slab where cracks developed during finishing and started leaking within 2 years of construction in spite of conventional water proofing with guarantee for 15 years.

Figure 8 shows cracks of width upto 2.4mm on surface and extending upto a depth 15 cm on a deck slab 75 cm thick due to not taking adequate care before and during finishing.

(a)

(b)

Figure 7. (a) Nozzles fixed along cracks in roof slab (b) Sealing of cracks with epoxy injection

j. Temperature of concrete

i. If temperature of concrete during placing and setting is very high this would increase the very early strength but may adversely affect the strength from about 7 days onwards. The explanation for this is that a rapid initial hydration appears to form products of a poorer physical structure, more porous so that a proportion of the pores will always remain unfilled. It follows from the gel/space ratio rule that this will lead to a lower strength compared with a less porous, though slowly hydrating cement paste in which a high gel/space ratio will eventually be reached [1].

   As per IS 7861-Part 1 [11] temperature of mixed concrete at the point of placing shall not be more than 40°C and not less than 5°C. However designers have been found to reduce the maximum temp of concrete to 30°C or even lower depending on particular functional requirement of the structures.

   Reaction between cement and water being exothermic and in case under high ambient temperature concrete produced attains a temperature higher than specified in contract, alternatives, such as pre-cooling of aggregates, water cooled with ice blocks, use of ice flakes through suitable conveyor arrangement etc may be adopted to bring the temperature of concrete within permissible limit.

   It has been noticed by the Author that at a Nuclear Power Plant site in India at sea coast in spite of using concrete of temperature not exceeding 21°C at point

Figure 8. Multiple cracks on top of a deck slab

of placing lot of cracks developed after finishing due to not taking adequate care in covering after finishing the concrete surface which was exposed to high surface wind due to proximity of site from sea apart from ambient temperature prevailing around 40°C.

ii. It is estimated that the temperature rise under adiabatic conditions is 12°C per 100 kg cement per cum of concrete regardless of the type of cement used, for cement contents between 300 and 600 kg/cum [1]. The choice of cement thus offers only a partial solution. The remedy, therefore lies in using a low cement content as well as in using blended cements because it is the Portland cement that is responsible for early heat generation, while pozzolanas react chemically more slowly. It follows that, using a low content of blended cement with a high proportion of pozzolanas, the maximum temperature rise can be reduced and its occurrence can be delayed. The benefit of the delay is that the concrete will have a higher tensile strength and be less prone to cracking.

iii. In case of thick and large RCC rafts/Pile caps the interior of the mass will heat up more than the exterior if the loss of heat at the surface is large. If difference in temperature between interior and exterior is more than 20°C cracking will develop. The solution to the problem is not to limit temperature rise in the interior but rather to prevent the heat loss at the surface. Thus the entire concrete mass is allowed to heat, more or less to the same degree and expand without restraint. With passage of time cooling will take place again more or less uniformly throughout and the structure would reach its final dimensions again without restraint.

To prevent large heat loss, the formwork on sides shall be kept in place for a few days and top surface of concrete shall be covered properly with polystyrene or urethane. Additional insulation would be required to be provided at edges and corners where heat loss occurs in more than one direction and also in other sensitive parts of the structure.

The temperature at various points should be monitored by installing Thermocouples. Insulation should be adjusted accordingly and maintained till temperature differential has been reduced to 10°C

Figure 9. Ponding on a pavement slab for curing

k. Proper curing

Curing is a very important aspect to ensure durability. During process of hydration, loss of water from green concrete is prevented by wet curing. Development of strength in concrete is very much affected without curing. A comparison between strength of concrete attained by air curing and water curing is attached in Figure A1 [1]. Arrangements should be made for a particular person on the contractor's staff to be responsible for curing [12].

Again curing helps concrete in the cover zone which protects the reinforcements from corrosion by ingress of corrosive agents. Where water is scarce and/or to achieve very fast progress water curing for specified No of days cannot be continued, membrane curing using approved quality material has been successfully adopted. Latex based curing compound is sprayed when evaporation rate is less than 1 kg/sqm/hr and when it is more resin based curing compound would be more suitable. Rate of application of compound should be not less than 0.5 kg/sqm. Efficacy of curing compound should be properly tested particularly when no water curing is resorted to.

In case of concrete pavements of long lengths cast daily by slipform paver, membrane curing is adopted as first step followed by water curing from next day. Water curing should be continued for at least 7 days in case of concrete with Ordinary Portland Cement (OPC) while this period should be extended by minimum 3 days in case of concrete with Portland Pozzolana Cement (PPC) and/or Silica Fume.

Figure 9 shows ponding on pavement slab,

Figure 10 shows poor quality of abutment wall curing and Figure 11 shows proper curing on vertical surfaces of precast culverts.

C. OTHER ISSUES RELATED TO DURABILITY OF CONCRETE STRUCTURES

i. Failure of foundations

a. Due to high chloride and sulphate content in soil and ground water shall be within limits specified in Table 4, IS 456- latest amendments [5], and on that basis type of cement recommended should be used. In case both chloride and sulphate content are high, recommendations in Note 7 at end of above Table should be followed regarding use of cement of special requirement.

The Author states below the experience in two projects with high chloride content in ground water and how the problems were solved:

Figure 10. Poor quality curing for abutment and return wall

Figure 11. Proper curing of precast concrete culverts cast vertically in yard

1. In a plot meant for construction of a multi-storeyed press building on pile foundation on land reclaimed from sea at Abudhabi, UAE during sub-soil investigation in 1978 sub-soil water sample tested both in one UK laboratory and in IIT , Mumbai indicated presence of 130,000 ppm (13 p.c) chloride. The problem was referred to NCCBM (formerly, Cement Research Institute) Ballavgarh as cast-in-situ driven or bored pile was not considered suitable for this soil condition. The Institute advised use of precast concrete piles so that pile concrete developed enough strength before installation and coming in contact with ground water with such high chloride content. In order to make up some time lost in investigations and find right solution to the sub-soil problem,

precast prestressed piles with steam curing was adopted. Figure 12 shows installation of a pile using a sophisticated pile driver.

2. Also at a Fertiliser plant site near coast at Andhra Pradesh where chloride content in ground water was high precast concrete piles of square section were installed. Figure 13 shows piles driven in place.

b. Run-up of sea water during monsoon/river water during high flood conditions may result in erosion/siltation and de-stabilisation of shoreline or bank causing havoc although during fair weather sea may look calm and shoreline may be 100m or more away from waves hitting plains. Similarly, except during monsoon in a perennial major river in India shoals/sand beds are seen occupying major width with flow at low velocity in a limited width only.

In order to ascertain the effect of such run-ups on shore line/bank model studies must be undertaken.

Figure 12. Precast prestressed concrete piles being driven at Abudhabi

Figure 13. Precast RCC piles driven at a fertiliser project in India

Figure 14(a) shows a sea side wall with ornamental railing etc completed before monsoon and Figure 14 (b) shows open foundation affected by scour resulting in tilt of wall and collapse in certain stretches due to run-up of sea water during monsoon. Structures were built in a hurry under instructions from client without any model study.

ii. Testing of ingredients and manufactured products used in permanent works

a. It shall be ensured that Manufacturers' Test Certificates (MTC) for all manufactured products e.g cement, flyash, bentonite powder, GGBS, construction chemicals, reinforcement bars, structural steel sections etc are received along with supply. Again, all such certificates shall be signed by Quality Control in-charge or Chemist of the laboratory with name and designation printed on the certificate.

(a)

(b)

Figure 14. (a) Completed sea side wall before monsoon (b) Sea side wall after failure of open foundation during monsoon

b. As per frequency agreed in approved Field Quality Plan for the project samples of materials for use in permanent works shall be sent to external approved laboratories which should preferably have accreditation of National Accreditation Bureau for Laboratories (NABL). Where such laboratory is not available, Govt Engg Colleges, CSIR approved laboratories, Central Soils and Materials Research Station (CSMRS), New Delhi, National Test Houses, NCCBM, Ballavgarh, Central Road Research Institute (CRRI) and similar institutes should preferably be engaged.

iii. Correct fixing and sizes of prestressing cables used in I-girders etc.

a. There is a general tendency among designers to provide minimum No of cables of maximum capacity being tempted to minimise requirements of sheathing, anchorages ,stressing and grouting efforts. In such attempt it is forgotten that against vertical/Y-Y axis the I-girder is weak in bending. As a result, if high capacity cables are not fixed in position along the desired profile properly and shifting of cables takes place during vibration of concrete resulting in eccentricity in X-X direction , the girder may fail. Figure 15 shows failure of a

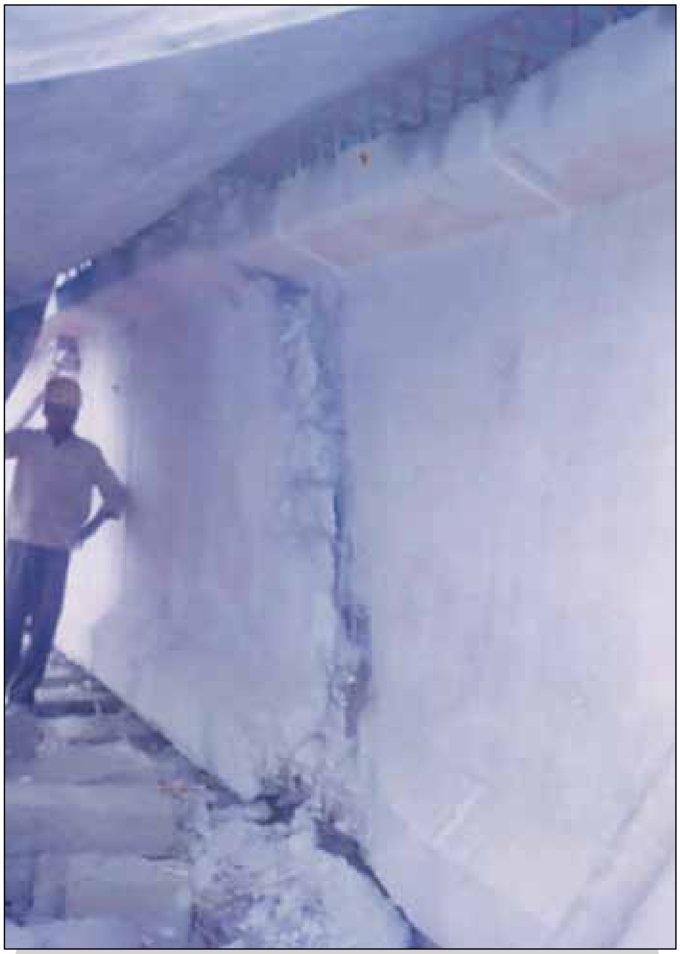

Figure 15. Failure of prestressed concrete girder during stressing

precast girder for a 2-lane flyover project with only 4 cables of high capacity, during stressing where curved profile of cables was maintained only by tying with binding wire. The girder had to be rejected.

In another flyover project involving cast-in-situ post-tensioned girders the Author noticed vertical crack and crushing of around 15 cm width of concrete of one of the four girders supporting the deck during stressing of the last out of 5 cables due to not fixing the cables in curved profile properly. After de-stressing of all cables about 45 cm width of concrete was cut and replaced by stitch concrete, re-stressed followed by casting of diaphragms and deck slab in next stage.

b. In this context it is essential that details of fixing cables in required profile be shown in relevant drawing for prestressed girders using welded U-bars in inverted position tightly fitting on sheathing on support bars used to maintain cable profile. If dependent on fixing of sheathing only by binding wires it is likely to allow displacement of cables from required profile when vibrator nozzle touches the sheathing and wires snap. Figure 16 shows sheathing for cables fixed in position in a girder with welded U-bars in inverted position.

c. Grouting of cables should be done properly by trained personnel using suitable equipment as in the past corrosion of cables have been reported due to inadequate grouting of

Figure 16. Fixing of HDPE sheathing for cables using inverted U-bars

cables in a few major bridge projects in coastal regions in particular, in India reducing service life of such structures to between 15 to 20 years only against minimum 60 years for such important bridges.

iv. Advantages of using precast concrete and vacuum processed concrete to extend durability.

a. Use of precast concrete technology has many advantages e.g superior quality, speed of construction, saving in material use, involvement of less labour, reduced life cycle cost and maintenance of structure. Since construction is moved to a great extent from project site to plant, construction site is much clean towards ease of living for residents in the near-by areas.

However, special care has to be taken in connections between precast elements with in-situ/stitch concrete, stressing or other means by proper detailing and sound construction so that the completed structure can safely carry design load including wind and seismic forces for sustainability and durability.

b. In Vacuum Processed Concrete (VPC) a mix with medium workability is placed in the forms in usual manner. Since fresh concrete contains a continuous system of water filled channels the application of a vacuum to the surface of the concrete results in a large amount of water being extracted from certain depth of concrete.

In other words 'water of workability' is removed when no longer required and air bubbles are removed only from the surface as they do not form a continuous system. The final w/c ratio before setting of concrete is thus reduced which largely controls the strength and durability of concrete,

VPC is commonly used in floors meant for industrial and heavy duty use in warehouses involving movement of heavy trucks, forklifts etc.

v. Prescriptive vis-a-vis performance specifications

Many project specifications continue to remain prescriptive in nature as a holdover from earlier days. These stifle innovation by limiting types and quantities of ingredients, mixture proportions and construction methods. Prescriptive specifications are often overly conservative, which can lead to higher costs and unexpected negative results- ultimately leading to unsatisfied customers [13].

The specification should be written in terse mandatory language with clear, measurable and achievable requirements. A performance specification is a set of instructions that outlines the functional requirements for hardened concrete depending on the application and it should clearly specify the test methods and the acceptance criteria that will be used to verify and enforce the requirements.

Such specifications will only be successful if the stakeholders in the concrete construction process are knowledgeable and cognisant of the needs and capabilities of the others [13].

The Author has seen in some tenders prepared for major bridges/marine projects in the recent past by reputed consultants in India use of volume batching of concrete with permission of Engineer, transport of concrete over a long distance by dumper, limit use of only OPC and river sand in concrete etc and most of the contents in tender documents are 20-25 years old used by 'cut and paste' method without even considering changes in relevant codes which practice has to change if durability is to be considered seriously.

vi. Limits of crack width should be strictly maintained as per stipulations of relevant code

vii. Limits of chloride and sulphate content in concrete shall be maintained as per stipulations of relevant code.

viii. Preventive maintenance of concrete

In earlier days belief was that unlike steel structure that had to be repeatedly painted, concrete needed no maintenance if designed as per relevant IS codes. But this does not hold good anymore.

Maintenance includes, as a first step, periodic inspection of the structure. The inspector must be familiar not only with concrete as a material but also with structural action. Reason for cracks is to be ascertained if due to overloading of a properly designed structure or structure is not strong enough or induced by corrosion of re-bars or by chemical action or by delayed formation of ettringite or by thermal effects.

Before taking up repair work , extent and causes of the problem are to be established to avoid repeated repair work. Details of repair work have not been included in this Paper.

D. CONCRETES AT VARIOUS STAGES OF DEVELOPMENT

Cement concrete is weak in tension and is prone to cracks at hydration stage unless proper precautions are taken. Concrete with such cracks is vulnerable to attack by aggressive ions, such as chlorides, sulphates, water, Co_2, oxygen, alkalis and acids as well as many natural or industrial liquids and gases.

Again, cement industry does not fit the contemporary picture of a sustainable industry because it uses raw materials and energy that are non-renewable, extracts its raw materials by mining and manufactures a product that cannot be recycled.

In order to improve various properties of concrete through on- going researches several types of concrete have been developed and are gradually being used commercially. Some such concretes are Reactive Powder Concrete, Geo-polymer Concrete and Ultra High Performance Concrete.

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Appendix

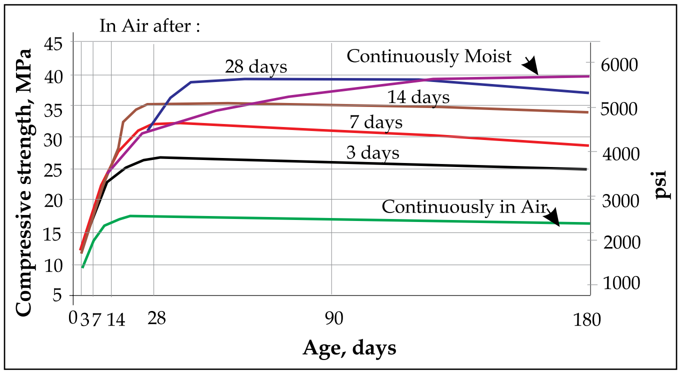

Figure A1. Influence of moist curing on the strength of concrete with a water/cement ratio of 0.50. Source: Figure 7.6 (Page 323)- Properties of Concrete by A.M.Neville, 4th Edition

Kartik Chandra Ta, BE(Civil), FICE(UK) retd, FIE(I),MIGS, Certified Lead Auditor on QMS to ISO 9001:2008 has total work experience of 52 years in design and construction of deep foundations, flyovers and bridges, marine structures, buildings with high quality finishes, Quality Control and Quality Assurance (QC/QA). He worked with Consulting Engineering Services in India and abroad for 19 years and with Simplex Infrastructures Ltd for 28 years in various positions including the post of Technical Director (QC/QA) at corporate level. At present he is working as Short Term Consultant to World Bank, Delhi office.

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Ashish Patil
Publisher, Printer and Editor