CHAPTER 2

STRENGTH AND DURABILITY OF CONCRETE

2.1 Quality assurance for concrete construction

A Quality Assurance scheme is a management system is a management system, which increases confidence that a material, product or service will conform to specified requirements. It outlines the commitments, policies, designated responsibilities and requirements of the owner.

QA scheme of one type or another is used. Depending on the value of the product and methods used in its manufacture, such schemes may themselves become extremely complex and involve individuals, who have little empathy for a particular material or process, even as being very competent in their understanding of others.

The assumptions made during the planning and the design, adequate QA measures shall be taken. The construction should results in satisfactory strength, serviceability and long term durability so as lower the overall life cycle cost.

QA in construction activity results to proper design, use of adequate materials and components to be supplied by the producers, proper workmanship in the execution of works by the contractor and ultimately, proper care during the use of structure, including timely maintenance and repair by the owner.

QA assure are both organizational and technical. Some common cases should be specified in a general QA plan, which shall identify the key elements, necessary to provide fitness of the structure, and the means by which they are to be provided, and the overall purpose to provide confidence that the realized project will work satisfactory in service, fulfilling intended needs.

The job of QA and QC would involve both the inputs as well as the outputs. Inputs are in the form of materials for concrete; workmanship in all stages of batching, mixing, transportation placing, compaction and curing; and the related plant, machinery and equipments; resulting in the output in the form of concrete in place.

QA plan shall define the tasks and responsibilities of all persons involved, adequate control and checking procedures and the organization and maintaining adequate documentation of the building process and its results, such documentation should generally include:

- ✓ Test reports and manufacturer's certificate for materials, concrete mix design
- ✓ Pour cards for site organization and clearance for concrete placement
- ✓ Record of site inspection of workmanship, field tests
- ✓ Non-conformance reports, change orders
- ✓ Quality control charts
- ✓ Statistical analysis

2.1.1 Need for quality Assurance

The quality necessary to give good performance and appearance throughout its intended life is attained.

- ✓ The client requires it in promoting his next engineering scheme
- ✓ The designer depends on it, for his reputation and professional satisfaction
- ✓ The materials producer is influenced by the quantity of work in his future sales.
- ✓ The building contractor also relies on it, to promote his organization in procuring future contracts, but his task is often complicated by the problems of time scheduling and costs

Most faults in structures are attributable to deign errors, and poor workmanship on site with only 10% being due to inadequate materials.

2.1.1.1 Causes of design faults may include:

- ✓ Mis-interpretation of the client's needs
- ✓ Lack of good communication between members of the design team
- ✓ Misinterpretation of design standards or codes of practice
- ✓ Use of incorrect or out-of-date data
- ✓ Production of and reference to inadequate and imprecise specifications

2.1.1.2 Causes of faults in construction may include:

- ✓ Misinterpretation of design drawings or specifications
- ✓ Lack of effective communication with suppliers and sub contractors
- ✓ Inefficient co-ordination of sub-contracted work
- ✓ Inadequate on-site supervision
- ✓ Poor workmanship due to inadequate skills and experience of the labour force satisfactory instructions

2.2 strength of concrete

The compressive strength of concrete is one of the most important and useful properties of concrete. In most structural applications concrete is employed primarily to resist compressive stresses. In most structural applications concrete is employed primarily to resist compressive stresses. In those cases where strength in tension or in shear is of primary importance, the compressive strength is frequently used as a measure of these properties.

The compressive strength of concrete is generally determined by testing cubes or cylinders made in laboratory or field or cores drilled from hardened concrete at site.

Strength of concrete is its resistance to rupture; It may be measured in a number of ways, such as Strength in compression, in tension, in shear or in flexure. All these indicate strength with Reference to a particular method of testing. When concrete fails under a compressive load the failure is essentially a mixture of crushing and shear failure.

The strength that may be developed by workable , properly placed mixture of cement, aggregate and water is influenced by:

- ✓ Ratio of cement to mixing water
- ✓ Ratio of cement to aggregate
- ✓ Grading, surface texture, shape, strength and stiffness of aggregate particles
- ✓ Maximum size of aggregate

2.3 Permeability of concrete

The rates at which liquids and gases can move in the concrete are determined by its permeability. Permeability of Concrete is often referred to as root cause for lack of durability. Permeability affects the way, in which concrete resists external attack, and the extent to which a concrete structure can be free of leaks. Theoretically, the introduction of aggregate of low permeability into cement paste. it is expected to reduce the permeability of the system, because the aggregate particles intercept the channels of flows and makes it take a circuitous route. Compared to neat cement paste, concrete with the same W/C ratio and degree of maturity, should give lower coefficient of permeability. But in practice, it is seen from test data it is not the case. The introduction of aggregate, particularly larger size of aggregates increases the permeability considerably.

The use of pozzolanic materials in optimum proportion reduces the permeability of concrete. This is evidently due to the conversion of calcium hydroxide, otherwise soluble and leachable, into cementitious product.

Though air-entrainment makes the concrete porous, when used upto 6%, makes the concrete more impervious, contrary to general belief.

High-pressure steam cured concretes in conjuction with crushed silica decreases the permeability. This is due to the formation of coarser C-S-H gel, lower drying shrinkage and accelerated conversion of Ca (OH)2 into cementitious products.

2.4 Thermal Properties

Thermal properties of concrete to understand the behavior of concrete to heating and cooling.The study of thermal properties of concrete is an important aspect while dealing with the durability of concrete.

Concrete is a material used in all climatic regions for all kinds of structures.The important properties that will be discussed are:

- ✓ Thermal conductivity
- ✓ Thermal diffusivity
- ✓ Specific heat
- ✓ Coefficient of thermal expansion

2.4.1 Thermal Conductivity

This measures the ability of material to conduct heat. Thermal conductivity is measured in joules per second per square meter of are conductivity of concrete depends on type of aggregate a of body when the temperature difference is 1degree C per meter thickness of the body.

The conductivity of concrete depends on type of aggregate moisture content, density and temperature of concrete. When the concrete is saturated, the conductivity ranges generally between about 1.4 to 3.4 J/S/^{m2}

2.4.2 Thermal Diffusivity

Diffusivity represents the rate at which temperature changes within the concrete mass. Diffusivity is simply related to the conductivity by the following equation:

Diffusivity=Conductivity/CP

Where C is the specific heat, and P is the density of Concrete. The range of diffusivity of concrete is between 0.002 to 0.006^{m2}/h

2.4.3 Specific heat

It is defined as the quantity of heat, required to raise the temperature of a unit mass of a material by one degree centigrade. The common range of values for concrete is between 840 to 1170 j/$^{kg3/C}$

2.4.4 Coefficient Thermal Expansion

It is defined as the change in unit length per degree change of temperature. In concrete, it depends upon the mix proportions. The coefficient of thermal expansion of hydrated cement paste varies between 11x10^-6 and 20x10^-6 per degree C. The coefficient of thermal expansion of aggregates varies between 5x10^6 and 12x10^-6 per degree C Limestone and Gabbros will have low values and gravel and Quartzite will have high values of coefficient of thermal expansion.

2.5 Cracking

Cracking will occur whenever the tensile strain, to which concrete is subjected, exceeds the tensile strain capacity of the concrete. The tensile strain capacity of concrete varies with age and with the rate of application of strain.

2.5.1 Classification of cracks

It may be classified in terms of their effects:

- ✓ Those cracks which indicate immediate structural distress
- ✓ Those cracks which may lead in the long run to a reduction of safety, through corrosion of steel
- ✓ Cracks which lead to malfunction of the structure, as evidenced by leakage, sound transfer, damage to finishes and unsatisfactory operation of windows and doors
- ✓ Cracks which are aesthetically unacceptable

Class I-Cracks leading to Structural Failure

Little difficulty arises in relation to this class. Those cracks that indicate that failure is near and that margin of safety are seriously reduced, may have formed in concrete, which was expected by the designer, to carry load in its un cracked condition .Such cracks are necessarily wide, and may lead to the detachment of parts of the structure.

Class II Cracks causing Corrosion

There is no unique relationship between crack width and the onset of corrosion. Part of the difficulty arises from the nature of cracks themselves. For flexural members, many cracks taper from a certain width at the surface of the concrete, the near zero width at the steel-concrete interface. However, flexural cracks that are controlled by the overall depth of the beam are not of the tapered shape, and it is likely that cracks due to temperature and shrinkage are nearer to being parallel sided. It has been assumed for many years that, since wider cracks would give easier access to aggressive substances, corrosion could be controlled by controlling crack widths and that permissible widths should be a function of how aggressive the environment was many complicated formulas for the calculation of crack widths in flexural members have been devised with the object of controlling corrosion. But extensive tests on beams in which the cracks are normal to the axis of the bars show evidence of any relationship between corrosion damage and crack width.

When cracks run along a bar, much more of the bar is in an exposed position, and it might be expected that there would be a closer relationship between crack width and corrosion in this situation. There is a little evidence however, that cracks whether transverse to the bars or running along the bars, pose any create risk of increased corrosion, if they are less than 0.3mm in width.

Some cracks, which are parallel to a bar, may have been caused by the corrosion of that bar. These cracks will widen as corrosion proceeds, and will eventually lead to spalling and exposure of the corroded bar. A crack of any width, which is judged to be brought about by corrosion, is an indication of a deteriorating structure, and therefore no minimum width, below which the crack is not significant, can be set. A crack that indicates the corrosion of the bar is actually showing that the corrosion will continue, unless positive measures are taken. Merely filling the crack will not achieve the result.

Class III-cracks affecting Function

The cracks in this class, which have the most serious consequences are those that allow liquid-retailing structures to leak, or that occur in roofs or other structures, intended to be waterproof. BS 8007 prescribes limiting crack widths and details methods of predicting the widths. The maximum design surface crack width, for direct tension and flexure or restrained temperature and moisture effects are:

Severe or very severe exposure-0.2mm

There are only limited test data available on what constitutes the limiting crack, for preventing leakage. Flow through a parallel-sided smooth crack, can be calculated in terms of head, crack width, crack length and fluid viscosity. The difficulty with concrete is that the cracks are not smooth or parallel-sided.

Class IV-cracks affecting appearance

For class 4cracks,it has been suggested that crack widths up to 0.3mm in width are acceptable aesthetically, but there are no good guidelines. Various attempts have been made to establish what constitutes an acceptable crack on an aesthetic basis, but in the end, there is no rational basis for aesthetic decisions. The aesthetic objection to cracks may be summarized as:

- Cracks cause alarm about the safety of the structure
- Cracks lower the visual acceptance of the structure (a) by modifying surface textures and damaging the visual effect intended by the designer and (b) by giving an appearance of cheapness or bad building.

Causes of cracking:

Cracking in plastic concrete may be due to: The removal of water from the top surface by evaporation exceeds the rate, at which bleed water is coming to the surface.	Cracking in Hardened concrete may be due to: The structural response to applied loads and external displacements
Early shrinkage of concrete	The intrinsic nature of the concrete and its constituent materials

Other types of cracks due to:

- ✓ Delayed curing
- ✓ Formwork movement
- ✓ Excess vibration
- ✓ Sub grade settlement
- ✓ Finishing
- ✓ Early frost damage
- ✓ Unsound materials
- ✓ Long-term drying shrinkage

2.6 Effects due Climate

The lack of durability of concrete on account of freezing and thawing action of frost is not of great importance to Indian conditions. But it is of greatest considerations in most part of the world.

The most severe climatic attack on concrete occurs, when concrete containing moisture is subjected to cycle of freezing and thawing. The capillary pores in the cement paste are of such a size that water in them will freeze, when the ambient temperature is below 0degree C.

The gel pores are so small that water in them does freeze at normal winter temperatures. As water, when freezing expands by 9% of its volume, excess water in the capillaries has to move. Since the cement paste is relatively impermeable high pressures are necessary to move the excess water even over quite small distances. For normal strength concrete, it has been found that movement of the order of 0.2mm is sufficient to require pressures which approach the tensile strength of the paste.

Concrete can be protected from freeze-thaw damage by the entrainment of the appropriate quantities of air distributed through the cement paste, with spacing between bubbles of not more than about 0.4mm. The air bubbles must remain partially empty, so that they can accommodate the excess water moved to them. This will generally be the case, since the bubbles constitute the coarsest pore system, and are therefore the first to, most moisture as the concrete dries. Fully saturated concrete, if permanently submerged, will not need protection against freezing, but concrete which has been saturated and is exposed to freezing as for example in the tidal range, may not be effectively protected by air entrainment.

For effective protection, an air entraining agent must be added to the mix, to entrain the appropriate amount of air, and to induce a bubble system, with an appropriate spacing. When AEA is used, it is only the amount of air entrained which can be measured in the wet concrete. The amount of air required is between 4-8%, depending on the maximum size of aggregate. Air is entrained during the mixing action, even when no AEA is added. The effect of AEA is to stabilize the air bubbles in the form desired.

More air is entrained with a larger dose of AEA but the effect is not linear and with most agents levels off larger doses. For mixes with higher slump, more air is entrained. It is difficult to entrain air is very stiff mixes; the grading and nature of the particles in the fine aggregates have a very marked effect, on the amount of air entrained. It has been shown that the sand is the most important single factor in air entrainment.

It has been suggested that if concrete can be so dense, that there are no inter-connected capillary pores, and then resistances to freeze- thaw deterioration will exist without the need for air entrainment.

The use of high cement content and low w/c ratio will lead in this direction as will the introduction of silica flume, but there is yet firm evidence to show that, it would be wise to dispense with air-entrainment, if freeze-thaw resistance is wanted.

2.7 Effects due to temperature

Temperatures of concrete, other than special refractory concrete, have to be kept below 300degrre C. Heat may affect concrete as result of:

- ✓ The removal of evaporable water
- ✓ The removable of combined water
- ✓ Alteration of cement paste
- ✓ Disruption from disparity of expansion and resulting thermal stress
- ✓ Alteration of aggregate
- ✓ Change of the bond between aggregate and paste

2.8 Effects due to Chemical

Some of the factors, which increases the vulnerability of concrete to external chemical attack:

- ✓ High porosity, and hence high permeability
- ✓ Improper choice of cement type for the conditions of exposure
- ✓ Inadequate curing prior to exposure
- ✓

- ✓ Exposure to alternate cycles of wetting and drying and to a lesser extent heating and cooling, with allowance for the fact that higher temperature increase reactivity
- ✓ Increased fluid velocities
- ✓ Expansive reactions of any sort which may cause cracking and any other physical phenomena, which lead to greater exposure of reactant surfaces
- ✓ Suction forces
- ✓ Unsatisfactory choice of shape and surface to volume ratios of concrete section

2.9 Effects due to Corrosion

Corrosion is defined as the process of deterioration (or destruction) and consequent loss of a solid metallic material, through an unwanted (or unintentional) chemical or electro-chemical attack by its environment, starting at its surface, is called Corrosion. Thus corrosion is a process of 'reverse of extraction of metals".

Corrosion Mechanism – Wet or Electro-Chemical Corrosion

Corrosion of steel concrete is an electro-chemical process. When there is a difference in electrical potential, along the reinforcement in concrete, an electro-chemical cell is set up. In the steel, one part becomes anode (an electrode with a +ve charge) and other part becomes cathode, (an electrode with a –ve charge) connected by electrolyte in the form of pore water, in the hardened cement paste. The +vely charged ferrous ions Fe^{+} at the anode pass into solution, while the –vely charged free electrons –pass through the steel into cathode, where they are absorbed by the constituents of the electrolyte, and combine with water and oxygen to form hydroxyl ions (OH).

These travel through the electrolyte and combine with the ferrous ions to form ferric hydroxide, which is converted by further oxidation to rust.

The reactions are described below:

Anodic Reactions:

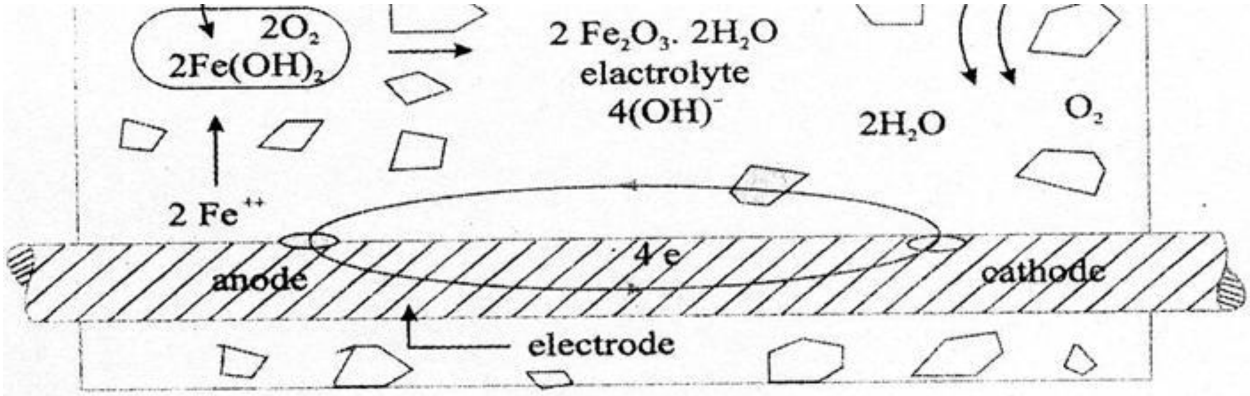
$$Fe \longrightarrow Fe^{++} + 2e^{-}$$

$$Fe^{++} + 2(OH)_2 \longrightarrow Fe(OH)_2$$

$$Fe(OH)_2.2H_2O + O_2 \longrightarrow 4Fe(OH)_3$$

Cathodic Reaction

$$4e^{-} + O_2 + H_2O \longrightarrow 4(OH)$$



Simplified model representing corrosion mechanism

It can be noted that no corrosion takes place if the concrete is dry probably below relative humidity of 60%, because enough water is not there to promote corrosion. it can also be noted that corrosion does not take place, id concrete is fully immersed in water, because diffusion of oxygen does not take place into the concrete. Probably the optimum relative humidity for corrosion is 70-80%

The products of corrosion occupy a volume as much as 6 times the original volume of steel, depending upon the oxidation state. Figure below shows the increase in volume of steel, depending upon the oxidation state.

it may be pointed out that though the 2 reactions Fe2 and OH originate iron the anode and cathode respectively, their combination occurs more commonly at the cathode, because the Sn. alert Fe2+ ions diffuse more rapidly than the larger OH ions. So, corrosion occurs at the anode, but rust is deposited at or near the cathode.

Increase the oxygen content has 2 effects:

(i) It forces the cathode reaction to the right, producing more OH- ions and

(ii) It removes more electrons and therefore, accelerates the corrosion at the anode.

Each of these effects, in turn, supplies more reactants for the forming reaction. Obviously, presence of oxygen greatly accelerates both corrosion and rust formation, with the corrosion occurring the entire anode, but the rust forming at the cathode.

2.10 Design and construction errors

Misconceptions of Structural Action

Design procedures often include simplifying assumptions as to the way, in which the final structure will behave. It the designer does not ensure that the structure can, in fact, behave in the assumed way, cracking occurs to the extent necessary. A common example is when moment free condition is assumed and not achieved. A wall-floor joint in a 1 Million Liter water tank is shown fig. In the design of the tank, this joint had been assumed to behave as a pin, but the face marked bitumen paint did not have enough separation.

As a result, when the tank wall rotated under water load, the faces came into contact and the corner behaved as a knee-joint, transmitting moment. The compression components of this moment produced a diagonal tensile

Resultant, which caused a substantial piece of un-reinforced concrete to spall off, as shown in figure and exposed reinforcement then corroded.

When connected members have very different rigidities forces may tend to migrate from the path, provided by the designer into an alternative rigid member.

The primary beam shown in the figure below as to transfer the negative moments from the secondary beams, to the supporting columns.

As the columns and the primary beams are both stiff members, this transfer involves a torque in the primary beam, for which torsion reinforcement is needed. When this reinforcement was omitted from the design, helical cracks appeared.

Reinforcement Detailing

Inadequate detailing of reinforcement is a wideparead cause of cracking and particularly of those severe cracks, which affect the limit state of collapse

Designers given the opportunity, learn from experience and in many organizations, this source of trouble is steadily reduced. Members, which appear to be particularly susceptible to severe cracking as a result of insufficient steel or broadly arranged steel, are those which carry local loads, such as corbles, supports for bridge bearings, walls supporting column bases, pre-stressing anchorages and column capitals.

Conventional drawings tend to ignore the physical size of the bars, and the limitations on bend shape in practical reinforcing. Equally important is the need, to ensure that the steel is incorporated in the way it was designed.

Extensive tests on corbles identified 6 different failure mechanisms, which may occur and against which, reinforcement is needed. An arrangement of reinforcing which takes account of these potential failure modes in shown in the figure below. A very common source of trouble arises from locating the outer edge of the bearing, beyond where the steel can possibly be located. The designer should ensure that with normal tolerances on steel bending and placing, there is still adequate steel located outside the edge of the bearing, when it is located at the extreme of its tolerance.

Some arrangements of reinforcement actually cracks, and these should be carefully avoided. For example severe cracking can be seen, when all the top bars in a slab are terminate at the same cross section.

Construction Errors

Construction & supervision deficiencies are the major cause of defects, leading to cracking. It has been found that 36% of the defects were due to these causes. A well-known expect on structural failures said that, he never found a failure caused by poor concrete, but he had never investigated one that did not contain poor or interior concrete. This comment related to collapses of structures, but when the definition of failure is extended as we are doing here, the quality of concrete does become much more important. For example, the protection afforded to steel is greatly of concrete depended on the compaction & curing of the cover concrete.

Survey revealed that construction defects could be grouped into 4 classes.

A. Deficiencies in the control of concrete materials, batching & mixing
- ✓ Use of salt water as mixing water
- ✓ Excess fines in the aggregates

B. Inadequate preparation before concreting.
- ✓ Salt water contamination of reinforcement
- ✓ Lack of cover to reinforcement

C. Inadequacies of placing & subsequent treatment
- ✓ Plastic cracking & settlement cracking
- ✓ Lack of curing

D. Faults of construction planning &procedure
- ✓ Overloading of members by construction loads
- ✓ Loading of partially constructed members
- ✓ Differential shrinkage between section of construction
- ✓ Omission of designed movement joints
- ✓ Unexpected behavior and restraint during prestressing

2.10 effects of cover thickness & cracking

In reinforced concrete structures, sufficient cover of concrete has to be provided to avoid exposure of reinforcement to aggressive environmental conditions and consequent rusting and deterioration of the cross sectional area in the structural elements. The most common construction defect, particularly in buildings, is lack of adequate thickness of cover.

It provides the nominal cover requirements to meet:

- ✓ The durability requirements
- ✓ Specified period of fire resistance

Requirements of concrete cover

- ✓ The protection of the steel in concrete against corrosion depends upon an adequate thickness of good quality of concrete