Chapter 2

Physical Causes

2.1 INTRODUCTION

Concrete is the most extensively used material for construction of various types of structures such as buildings, bridges, dams, jetty, docks, roads, etc. Normally much emphasis is given on concrete compressive strength rather than on environmental factors, which are known to affect the concrete durability. This is one of the main reasons for serious deterioration of concrete structures mainly reinforced concrete structures. Maintenance and repair/rehabilitation of constructed facilities is presently the most significant challenge facing the concrete industry, the issue of durability has replaced concerns about strength as the most pressing problem of the day.

2.2 DURABILITY ASPECT OF CONCRETE

Concrete is said to be durable, if it withstands the conditions for which it has been planned/designed, without deterioration, over a period of intended service life. The term durability of concrete is used to characterize, in broad terms, the resistance of concrete to a variety of physical or chemical attacks due to internal or external causes. The internal causes include alkali aggregate reaction, volume change due to differences in thermal properties of aggregate and cement paste and above all the permeability of concrete. The external causes may be due to weathering, occurrence of extreme temperature variations, abrasion, and electrolytic action and attack by natural or industrial liquids and gases The environmental penetration by water, chlorides, sulphates, carbon dioxide and oxygen into reinforcement affect the durability of concrete. In general, the following factors influence the durability of the concrete:

- Water–cement ratio and water content
- Curing of concrete
- Cover to reinforcement
- Cement content and its properties
- Aggregates
- Mix design
- Workability
- Use of admixtures
- Thermal incompatibility of concrete constituents
- Transition zone between aggregate and cement matrix
- Environmental interaction
- Condition of reinforcing bars used.

Each of these factors, jointly or in isolation, controls the susceptibility to deterioration mechanism in concrete. All other factors mentioned above except cover to reinforcement and condition of reinforcing bars, control the pore structure of the concrete, which are directly related to the permeation properties. Therefore, measurement of permeation properties of concrete would result in assessment of durability of concrete. Permeability determines the following:

- Saturation of concrete with water
- Ingress of moisture and air
- Corrosion of steel
- Cracking and spelling of cover concrete
- Water tightness of the structure
- Thermal insulation properties.

2.2.1 Changes in the IS:456-2000 in Terms of Durability

Some significant following changes were made in IS:456-2000 version to improve durability of concrete structures:

- All three grades of OPC, 33 grade, 43 grade, 53 grade and sulphate resisting Portland cement have been included.
- Minimum grade of concrete for RCC work is M20.
- The permissible limits for solids in water have been modified keeping in view the durability requirements.
- The clause of admixtures has been modified and quality control aspect, while use of admixtures is emphasized.
- Durability clause has been enlarged to include detailed guidance concerning the factors affecting durability.
- The table of exposure conditions has been modified to include severe and extreme exposure conditions.
- This clause also covers requirements for shape and size of member, depth of concrete cover (minimum cover to reinforcement), concrete quality, requirement against exposure to aggressive chemicals and sulphate attack, minimum cement requirement and maximum w/c ratio, limits of chloride content, alkali silica reaction, and importance of compaction, finishing and curing.
- Clause on quality assurance measures has been incorporated.
- Cover to reinforcement has been specified, based on durability for different exposure conditions. This is one of the most important stipulations made basically on durability considerations.

Now, again some more changes will be required in provisions of IS:2000 code, based on experience gained in intervening period.

2.2.2 Protective Measures for Durable Design

The following measures need to be taken for durable design of any structure:

- Use of selected structural formwork
- Proper concrete composition including special additions of admixtures
- Proper reinforcement detailing including minimum concrete cover
- A special skin quality concrete including skin reinforcement
- Limiting or avoiding crack development and limiting crack widths
- Provision of coatings as additional protective measures
- Inspection and maintenance procedures including monitoring procedures to be specified
- Special active protective measures such as cathodic protection or monitoring by way of sensors.

2.3 MAJOR CAUSES FOR DISTRESS IN CONCRETE

Once the evaluation phase is over for a structure, the next step is to establish the cause or causes for the damage that has been detected. Since many of the systems might have been caused by more than one mechanism acting upon the concrete, it is necessary to have an understanding of the basic underlying causes of damage and deterioration. Distress and deterioration in concrete structures may arise from various reasons as brought out below:

- Faulty planning and designing: Wrong mix proportion, lack of protection, inadequate joint provision and under-designed structures.
- Use of inferior materials: Partially hydrated cement, contaminated aggregates, and contaminated water.
- Poor construction practices: Faulty formwork, improper placing, improper compacting, inadequate curing, lack of proper supervision and quality control at site.
- Environmental effects: Thermal movement, moisture movement, freezing and thawing and surface erosion.
- Chemical effects: Carbonation, chloride intrusion and acid attack.
- Internal stresses: Fire, sulphate attack, alkali-aggregate reaction and volume change.
- Abuse of structures: Lack of maintenance, vandalism.
- Mechanical causes: Overloading, abrasion or wear.

The following are the major causes of distress in concrete structures:

- Structural deficiency arising out of faulty designing and detailing as well as wrong assumption in the loading criteria
- Structural deficiency due to defects in construction, use of inferior and substandard materials
- Damages caused due to fire, floods, tsunami and earthquakes, etc.
- Physical deterioration and creep
- Chemical deterioration, and marine environments
- Damages caused due to abrasion, wear and tear
- Damages due to impact, vibration, fatigue
- Settlement of foundation, thermal expansion.

2.3.1 Types of Failures/Damages in Concrete Structures

Deterioration of concrete is an extremely complex subject. It would be simplistic to suggest that it will be possible to identify exactly a specific, single cause of deterioration for every symptom detected during an evaluation of a structure. In most cases, the damage detected will be the result of more than one mechanism. For example, corrosion of reinforcing steel may open cracks that allow moisture greater access to the interior of the concrete. The moisture could lead to additional damage by freezing and thawing. Inspite of the complexity of several causes working simultaneously, given a basic understanding of the various damage causing mechanisms, it should be possible, in most cases, to determine the primary cause or causes of the damage seen on a particular structure and to make intelligent choices concerning selection of repair materials and methods. A structure can be considered to have failed or damaged, not merely when it collapses, but also in cases when it fails to perform the functions for which it was designed. Damage to structures can be broadly classified as under:

- Total or partial collapse
- Dissolution of materials
- Cracking (including pattern cracks)
- Spalling of materials resulting in reduction in size of members
- Deformations such as deflection, buckling, twisting, and distortion.

2.3.2 Causes for Deterioration of Concrete

The common causes are brought out below:

- Accidental loadings
- Chemical reactions:
  - i. Acid attack
  - ii. Aggressive water attack
  - iii. Alkali-carbonate rock reaction
  - iv. Alkali-silica reaction
  - v. Miscellaneous chemical attack
  - vi. Sulphate attack
- Construction errors
- Corrosion of embedded metals
- Design errors:
  - i. Inadequate structural design
  - ii. Poor design details

- Erosion:
  - i. Abrasion
  - ii. Cavitation
- Freezing and thawing
- Settlement and movement
- Shrinkage:
  - i. Plastic
  - ii. Drying
- Temperature changes:
  - i. Internally generated
  - ii. Externally generated
  - iii. Fire
- Weathering

2.4 SHRINKAGE PROBLEM IN CONCRETE

Shrinkage is caused by the loss of moisture from concrete. It may be divided into two general categories:

i. Plastic shrinkage which occurs before setting

ii. Drying shrinkage which occurs after setting.

Shrinkage in concrete means moisture movement in concrete. It may be defined as the volume changes in concrete due to loss of water or moisture caused by evaporation or hydration of cement or carbonation. In practice, shrinkage is simply measured as linear strain. Its units are thus mm/mm. Shrinkage can be further classified into the following categories:

- Plastic shrinkage
- Drying shrinkage
- Autogenous shrinkage
- Carbonation shrinkage

2.4.1 Plastic Shrinkage

Mechanism

It is a fact that during the period between placing and setting, most concrete exhibits bleeding to some degree. Bleeding is the appearance of moisture on the surface of concrete; it is caused by the settling of the heavier components of the mixture. Usually, the bleed water evaporates slowly from the concrete surface. When environmental conditions are such that evaporation is occurring faster than water is being supplied to the surface by the bleeding, high tensile stresses may develop. These stresses can lead to the development of cracks on the concrete surface. Typically, the cracks are isolated rather than patterned. These cracks are generally wide and shallow. The reasons and characteristics are brought out below:

- The primary cause of plastic shrinkage crack is the rapid evaporation of water from the surface of concrete.
- Plastic shrinkage cracks occur within few hours after placing concrete, while it is still plastic and before it attained any significant strength.
- These occur almost entirely on horizontal surfaces exposed to the atmosphere. It is observed that the cracks developed are parallel to one another and normally spaced 0.3 m to 1.0 m apart.
- They can be deep and the width varies from 0.1 mm to 3 mm.
- The magnitude of plastic shrinkage and plastic shrinkage cracks are depending upon ambient temperature, relative humidity and wind velocity.
- It depends on the rate of evaporation of water (bleeding) from the surface of concrete (1 kg/m^2/hr).

The following measures could be taken to reduce or eliminate plastic shrinkage cracks:

- Moistening the subgrade and formworks
- Erecting temporary wind-breakers to reduce the wind velocity over concrete
- Erection of temporary roof to protect green concrete from the hot sun
- Reduction of the time between placing and finishing of concrete. If there is delay, the concrete surface should be covered with polythene sheets.
- Evaporation to be minimized by covering concrete with burlap, fog spray and curing compound.

In addition, it will be beneficial to minimize the loss of moisture from the concrete surface between placing and finishing. Finally, curing should be started as soon as practicable. If cracking caused by plastic shrinkage does occur and if it is detected early enough, revibration and refinishing of the cracked area will resolve the immediate problem of the cracks.

Plastic Settlement Cracks and Plastic Cracks

When there is any obstruction to uniform settlement by way of reinforcement or large pieces of aggregate, then it creates some voids or cracks in concrete. This is called *plastic settlement cracks.* The characteristics and reasons are explained below:

- This happens generally in a deep beam. These settlement cracks and voids are so severe, it needs grouting to seal them off.
- The air-entraining admixtures or water-reducing admixtures can be used for preventing such cracks.
- Normally plastic cracks develop before the concrete has hardened, i.e. between 1 and 8 hours of placement of concrete.
- As the evaporation of water takes place from the surface of concrete, it contracts resulting inducement of tensile stress in concrete causing cracks.
- These cracks can be prevented by restricting the rate of evaporation of water from the surface to be less than 0.5 kg/hr/m^2.

2.4.2 Drying Shrinkage

Mechanism

Drying shrinkage is a long term change in the volume of concrete caused by the loss of moisture. If the shrinkage could take place without restraint, there would be no damage to the concrete. However, the concrete in a structure is always subject to some degree of restraint by foundation, or by another part of the structure, or the difference in shrinkage between the concrete at the surface and that in the interior of a member. This restraint may also be attributed to purely physical conditions such as the placement of footing on a raft foundation or chemical bonding of new concrete to earlier placements or both. The combination of shrinkage and restraints cause tensile stresses that can ultimately lead to cracking.

Symptoms

Visual examination shows typical cracks that are characterized by their fineness and absence of any indication of movement. They are usually shallow, a few centimeters in depth. The crack pattern is typically orthogonal or blocky. This type of surface cracking should not be confused with thermally induced deep cracking, which occurs when dimensional change is restrained in newly placed concrete by rigid foundations or old lifts of concrete. The characteristics and reasons of this crack are listed below:

- It is caused by physical loss (evaporation) and chemical loss (hydration) of water during the hardening process and exposure to unsaturated air.
- The resulting reduction in volume can cause cracks, if the concrete is restrained and tensile strength exceeded.
- These cracks normally appear at about 7–10 days after concreting and around 80% of drying shrinkage takes place by about a year.
- It is influenced by a number of factors, such as cement content, water content, aggregates, curing, humidity and temperature.
- Drying shrinkage cracks are generally confined to nonstructural members like floor toppings, screeds and rendering, and parapet walls.
- The total drying shrinkage is made up of irreversible and reversible shrinkage. On initial drying out, an appreciable amount of total shrinkage is irreversible, but after several cycles of wetting and drying, the shrinkage becomes entirely reversible.

Some of the preventive measures are as follows:

- Use of minimum water content
- Use of highest possible aggregate content
- Providing adequate and early curing
- Eliminating external restraints as much as possible
- Providing sufficiently close-spaced reinforcement.

Additionally, placing the concrete at as low a temperature as practical; dampening the subgrade and the forms; dampening aggregates, if they are dry and absorptive; and providing an adequate amount of reinforcement to distribute and reduce size of cracks that do occur. Restraint can be reduced by providing adequate contraction joints.

2.4.3 Autogenous Shrinkage

The reasons and characteristics of autogenous shrinkage are as follows:

- If no movement of water to or from the set paste of concrete is allowed, then the shrinkage developed is known as autogenous shrinkage.
- The shrinkage is caused by the loss of water consumed or used up in the hydration of cement.
- The magnitude of this shrinkage is very small and not of much significance.

2.4.4 Carbonation Shrinkage

The characteristics are as follows:

- Carbonation is the reaction of carbon dioxide present in the atmosphere, with the hydrated cement materials in the presence of moisture.
- The simultaneous reaction of CO_2 with hydrated cement minerals in concrete induces contraction of concrete, which is known as carbonation shrinkage.

2.5 FREEZE AND THAW ON CONCRETE

The disintegration or deterioration takes place when the following conditions are present:

- Freezing and thawing temperature cycles within the concrete
- Porous concrete that absorbs water (water filled pores and capillaries).

2.5.1 Mechanism of Deterioration

As the temperature of a critically saturated concrete is lowered during cold weather, the freezable water held in the capillary pores of cement paste and aggregates expands upon freezing. If subsequent thawing is followed by refreezing, the concrete is further expanded, so that repeated cycles of freezing and thawing have a cumulative effect. By their very nature, concrete hydraulic structures are vulnerable to freezing and thawing simply because there is ample opportunity for portions of this structure to become critically saturated. Concrete is especially vulnerable in area of fluctuating water levels or under spraying conditions. Exposure in such areas as the tops of walls, piers, parapets, and slabs enhances the vulnerability of concrete to the harmful effects of repeated cycles of freezing and thawing and may lead to pitting and scaling. It involves the development of osmotic and hydraulic pressure during freezing, principally in the paste, similar to ordinary frost action. The freezing and thawing mechanism action is brought out below:

- Freeze and thaw deterioration generally occurs on horizontal surfaces that are exposed to water, or on vertical surfaces that are at the water line in submerged portions of structures.
- The freezing water contained in the pore structure expands, as it is converted into ice. The expansion causes localized tension forces that fracture the surrounding concrete matrix.
- The first stage is the development of fine closely spaced cracks parallel to the edge of the exposed concrete.
- The concrete soon becomes filled with a dark deposit of calcium carbonate and are commonly called D-cracks.

- As the deterioration continues, small pieces of concrete between the cracks separate from the body of concrete.
- The deterioration is reduced as the water–cement ratio is reduced, but the only positive way to prevent the problem is to protect concrete by the adequate air-void system.
- The superiority of air entrained with respect to freezing and thawing action is evident from standard graph available.
- Visual examination of concrete damaged by freezing and thawing may reveal symptoms ranging from surface scaling to extensive disintegration.

2.5.2 Preventive Measures

The following remedial measures may be taken against freezing damage:

- Water–cement ratio and total water content used should be as lowest as practicable.
- Adequate air entraining has found to be effective in controlling the freezing damage.
- Use of durable aggregate is also useful to check the freezing effect.
- Adequate curing of concrete prior to exposure to freezing conditions is also important.
- Designing the structure to minimize the exposure to moisture, as for example, providing positive drainage rather than flat surfaces, wherever possible.

2.5.3 Rate of Freeze–Thaw Deterioration

This depends on the following factors:

- Increased porosity (increases rate)
- Increased moisture saturation (increases rate)
- Increased number of freeze-thaw cycles (increases rate)
- Air entrainment (reduces rate)
- Horizontal surfaces that trap standing water (increases rate)
- Aggregate with small capillary structure and high absorption (increases rate).

D-cracking is normally linked to aggregate. It consists of development of fine cracks near free edges of slabs, but the initial cracking starts lower in the slab where moisture accumulates and the course aggregate becomes saturated to the critical level. With cyclic freezing and thawing, the mortar surrounding the aggregate fails leading to the D-cracking. Aggregate of sedimentary, calcareous or siliceous origin (gravel, crushed rock) leads to D-cracking due to frost action.

2.6 WEATHERING ACTION ON CONCRETE

Weathering is normally referred to as a cause of deterioration of concrete. It defines a change in color, texture, strength, chemical composition, or other properties of a natural or artificial material due to the action of weather. The environmental factors that can cause cracking include the following:

- Freezing and thawing
- Wetting and drying
- Cooling and heating.

The salient features of weathering action on concrete are as follows:

- The damage from freezing and thawing is the common weather related physical deterioration.
- Other weathering processes that may cause cracking in concrete are alternate wetting and drying, and heating and cooling.
- If the volume changes due to these processes are excessive, cracks may develop and give the impression that they are on the verge of disintegration.
- The damage due to these factors may appear in the form of general flacking and spalling of concrete from the surface of concrete.
- Concrete generally loses strength with increase in temperature about 300 degree centigrade, damage being greater with aggregate having high coefficient of thermal expansion.

2.7 CRAZING ON CONCRETE

The characteristics of crazing on concrete are as follows:

- Crazing is the development of a network of fine random cracks on the surface of concrete or mortar caused by shrinkage and usually related to finishing and curing procedures.
- Excessive floating and troweling bring water, cement and dust from the aggregates to the surface to produce a surface skin, which has a higher drying shrinkage than the underlying concrete.
- Spreading dry cement on a surface that is too wet to trowel, and sprinkling water on concrete that is too dry to trowel, both produce a skin likely to suffer from crazing.
- Use of highly absorptive aggregates batched in the dry state may contribute to crazing.
- The use of overwet concrete contributes to all the problems associated with drying shrinkage, since shrinkage is almost directly proportional to the amount of mixing water in concrete.
- Improper curing can cause crazing, even if the concrete is properly batched, mixed, placed and finished.
- Use of unvented heater during the curing period is also a cause of crazing.

2.7.1 Preventive Measures

Some of the preventive measures include the following:

- Damping the subgrade before placing the concrete
- Avoiding overfinishing of the surface
- Delaying troweling until the surface moisture has disappeared
- Avoiding sprinkling of dry cement or water on the surface during finishing operation
- Starting curing as soon as possible
- Avoiding use of unvented heaters
- Batching of absorptive aggregates in a moist condition
- Avoiding higher temperature differentials between concrete and curing water.

2.8 HONEYCOMBING ON CONCRETE

Honeycomb consists of exposed pockets of coarse aggregates not covered by a surface layer of mortar. This may be caused due to inadequate consolidation, presence of excess water in concrete or use of leaky formworks, which allow the mortar to escape.

2.8.1 Preventive Measures

Some of the preventive measures are brought out below:

- Good construction practices need to be followed strictly
- Workable concrete to be used
- Good forms (tight and leak-proof) to be used
- Proper vibration (compaction) to be ensured
- Placing of concrete need to be planned in a sequence.

2.9 SWELLING EFFECT OF CONCRETE

Concrete used continuously in water from the time of casting exhibits a net increase in its volume and weight. This increase in volume due to continued hydration of cement is known as swelling. The swelling is due to the absorption of water by the cement gel.

2.10 POP OUTS ON CONCRETE

A pop out is a conical-shaped hole in the surface with a portion of coarse aggregate particle exposed. These occur outdoors on the horizontal and vertical surfaces. They are caused by freezing of water in aggregate particles that have an internal pore structure, which causes them to expand unduly upon freezing. Normally pop outs do not appear during construction, but they start appearing during the first winter following construction and may continue to form for several years.

These do not harm the concrete, but they are unsightly. The rocks that have produced pop outs include chart, shale, clay stone, mudstone, argillaceous limestone, and siltstones. Pop outs can be prevented only by avoiding aggregates which cause them.

2.11 CREEP PROBLEM ON CONCRETE

Concrete, brickwork and timber when subjected to sustained loads not only undergo instantaneous elastic deformation, but also exhibit a time-dependent deformation known as creep. In concrete, creep results in a sustained increase in elastic deformation, which sometimes leads to formation of cracks in brick masonry of framed and load bearing structures. Deferring the removal of centering and application of external load can reduce it. However, when sustained load is removed, the strain decreases immediately by an amount equal to the elastic strain at the given age (instantaneous recovery). This instantaneous recovery is then followed by a gradual decrease in strain, called creep recovery, which is a part of total creep strain suffered by the concrete. If a loaded concrete specimen is viewed as being subjected to a constant strain, the creep decreases the stress progressively with time. This is called relaxation. While 80–85% shrinkage strains occur in six months, only about 75% of creep strains occur in a year.

2.11.1 Various Influencing Factors

All the factors which influence shrinkage also influence creep, which includes the following:

- Types of aggregate
- Type of cement and cement content
- Admixtures used
- Entrained air
- Mix proportions
- Mixing time
- Age of concrete
- Level of sustained stress
- Ambient humidity
- Temperature
- Size of the specimen.

2.12 ABRASION, EROSION AND CAVITATION ON CONCRETE

The terms abrasion, erosion and cavitation are explained below:

- Abrasion refers to wearing away of the surface by friction.
- Erosion refers to wearing away of the surface by fluids.
- Cavitation refers to the damage due to nonlinear flow of water at velocities greater than 12 m/sec.
- The concrete used in roads, floors, pavements and also the one used in the hydraulic structures should exhibit resistance against abrasion, erosion, and cavitation.
- The more the compressive strength, the higher is the resistance to abrasion, erosion and cavitation.
- Due to abrasion, dusting problem arises, which may be harmful in many situations, e.g. industrial floors having material handling system or robots.
- If the aggregate in concrete is wear resistant, it is the property of cement matrix that controls the abrasion resistance.
- Use of steel fibers in cement matrix improves abrasion resistance of concrete and also polymer based systems when applied to concrete improve the abrasion resistance.
- The shape and surface texture of aggregate play an important role in abrasion resistance of the concrete.
- Epoxy screeding and polymer application to the surface is said to be effective against cavitation.

2.13 TEMPERATURE VARIATION

Change in temperature causes a corresponding change in volume of concrete. As was true for moisture-induced volume change, temperature-induced volume change must be combined with restraint before damage can occur.

Basically, there are three temperature change phenomena that may cause damage to concrete. Firstly, there are temperature changes that are generated internally by the heat of hydration of cement in large placements. Secondly, there are temperature changes generated by variations in climatic conditions. Finally, there is a special case of externally generated temperature change-fire damage. For internally and externally generated temperature changes, different mechanisms, symptoms and prevention methods are there.

2.14 FIRE EFFECT ON CONCRETE

Concrete structure gets damaged due to fire, the extent of which depends upon the intensity and duration of the fire. The principal types of damage are:

- Reduction in strength of concrete
- Cracking and spalling of concrete
- Deflection and deformation of members
- Discoloration
- Other miscellaneous functional failures.

Though concrete is not a refractory material, but it has good fire resistance properties. Fire resistance of concrete is determined by three main factors:

1. The capacity of concrete to withstand heat.
2. The conductivity of concrete to heat.
3. The coefficient of thermal expansion of concrete.

In case of reinforced concrete, the fire resistance is not only dependent upon the type of concrete, but also on the thickness of cover to reinforcement. The fire introduces high temperature gradients and as a result of it, the surface layers tend to separate and spill off from the cooler interior. Due to the heating of reinforcement and aggregates, the expansion takes place both laterally and longitudinally of the reinforcement bars resulting in loss of bond and strength of reinforcement. The effect of increase in temperature on the strength of concrete is not much up to a temperature of about 300 degree centigrade, but above 300 degree centigrade, definite loss of strength takes place.

In mortar and concrete, the aggregate undergoes a progressive expansion on heating, while the hydrated products of the set cement, beyond the point of maximum expansion shrinks. These two opposite actions progressively weaken and crack the concrete. Quartz, the principal mineral in sand, granite and gravel expands steadily up to about 573 degree centigrade. At this temperature it undergoes a sudden expansion of 0.85%. This expansion has a disruptive action on the stability of concrete. By the use of fire resistance aggregates, the fire resistance capacity of concrete improves. The best fire resistant aggregates, amongst the igneous rocks are basalt and dolerite.

Limestone expands steadily until temperature reaches to about 900 degree centigrade and then begins to decompose; hence it has been found that dense limestone is considered as a good fire resistant aggregate. Blast furnace slag aggregate and broken bricks aggregate are good resistant to fire. The large series of tests indicated that even the best fire resistant concrete have been found to fail, if the concrete is exposed for a considerable period to a temperature exceeding 900 degree centigrade, while serious reduction in strength occurs at a temperature of about 600 degree centigrade.

2.15 THERMAL MOVEMENT IN CONCRETE

Thermal movement in concrete occurs due to considerable amount of heat generated by heat of hydration, atmospheric temperature and external fire. Due to thermal movement, changes in shape and volume of concrete cause cracks on the concrete structures. The extent of temperature rise depends on the properties of cement used and the shape and size of the components. The heat of hydration may not be significant, but in mass concrete works, it is an important factor to be contended with. The control of heat and avoidance of cracks to maintain the integrity of concrete structures is a subject in itself.

2.15.1 Preventive Measures

Some of the preventive measures include the following:

- Use of Pozzolona cement
- Use of low heat cement
- Precooling of aggregates and mixing with water
- Post cooling of concrete by circulating refrigerated water through pipes embedded in the body of concrete
- Providing joints to relieve the restrains in the structure
- Providing adequate reinforcement to distribute the stresses
- Providing suitable insulation covers.

2.16 SUBGRADE MOVEMENT

If there are local soft pockets in subgrade on which concrete is placed or if there are any pockets or hollows under the building paper, there will be localized settlement of concrete due to the weight of the plastic mass. If this settlement occurs after finishing of the concrete surface, cracks will appear. The occurrence can be prevented by proper attention to compacting and draining the subgrade.

2.17 FORMWORK MOVEMENT

Movement of formwork during the period while the concrete is going from a fluid to rigid material may induce cracking and separation with concrete. A crack open to the surface will allow excess of water to the interior of the concrete. All internal voids may give rise to freezing or corrosion problems, if the voids become saturated. Any movement of formwork, which occurs between the time when concrete begins to lose its fluidity and the time when it has fully set, causes internal cracks to appear in the structure. These cracks are potentially dangerous in the sense that they form a water pocket in the concrete mass, which upon freezing will spall the concrete surface. Rebar corrosion can also result from such water pockets. Such cracks can be prevented by a proper design of the forms, with respect to details and deflections.

2.18 SETTLEMENT AND MOVEMENT

There are two types of mechanism of settlement and movement in concrete structural members. They are:

1. Differential movement
2. Subsidence

Their mechanism is different and symptoms and prevention or corrective measures are also different.

2.19 FOUNDATION SETTLEMENT

Shear cracks occur when there is a differential settlement of foundation. Shear failure is predominant in made-up ground. Some of the preventive measures are brought out below:

- Providing an impermeable apron all around the building
- Prevention of water stagnation around the building
- Providing adequate drainage system
- Avoiding the plantation of fast growing trees in the immediate vicinity of the building.

2.20 DESIGN ERRORS

Design errors may be divided into two general types as brought out below:

1. The first type are those resulting from inadequate structural design. This type has got special mechanism, symptoms and prevention methods. In fact, inadequate design is best prevented by thorough and careful review of all the design calculations, preferably by a third party proof checking and corrective action taken accordingly.
2. The second type are those resulting from poor design details. In the existing structures, problems from poor detailing should be handled by correcting the detailing and not by simply responding to the symptoms.

Poor design details may be due to the following factors:

- Abrupt changes in section
- Insufficient reinforcement at re-entrant corners and openings
- Inadequate provision for deflection
- Inadequate provision for drainage
- Insufficient spacing in expansion joints/ inadequately designed expansion joints
- Incompatibility of materials
- Neglect of creep effect
- Rigid joints between precast units
- Unanticipated shear stresses in piers, columns, or abutments
- Inadequate joint spacing in slabs.

The design and detailing errors that may cause an unacceptable cracking are as follows:

- Improper selection and/or detailing of reinforcement
- Use of poor detailed re-entrant corners in walls, precast members and slabs
- Restraint of members subjected to volume changes due to variations in temperature and moisture
- Lack of adequate contraction joints
- Improper design of foundations results in differential settlement within the structure
- Re-entrant corners provide a location for stress concentration and these are main location of initial cracks, as in the case of window and door openings in concrete walls and beams.

The structures, in which cracking may cause major problem of serviceability need special care in the design and detailing. These structures also need continuous inspection during all the phases of construction.

2.21 CONSTRUCTION ERRORS

Failure to follow specified procedures and good engineering practices or outright carelessness may lead to a number of conditions, which may be grouped together as *construction errors.* Typically, most of these errors may not always lead directly to failure or deterioration of concrete. Instead, they definitely enhance the adverse impact of other mechanisms. The errors normally encountered are as below:

- Adding more water to concrete
- Improper alignment of formwork
- Improper consolidation
- Improper curing
- Improper location of reinforcing bar
- Premature removal of shores or re-shores
- Settling of the concrete
- Settling of the subgrade
- Improper vibration of freshly placed concrete
- Improper finishing of flat work.

2.22 CRACKS DUE TO CONSTRUCTION OVERLOAD

The load induced during construction can be far more severe than those experienced in service. Unfortunately, these conditions may occur at the early ages, when concrete is most susceptible to damage and often result in permanent damage in terms of cracks. A common error occurs when the precast members are not properly supported during transportation and erection. The use of arbitrary or convenient lifting points may cause severe damage/complete collapse of structure in certain cases. A big element lowered too fast, and stopped suddenly carries significant momentum, which is translated into an impact load that may be several times the dead weight of the element. Storage of materials and equipment can easily result in loading conditions during construction for more severe than any load for which the structure is designed. Damage from un-intentional construction overloads can be prevented only if the designers provide information on load limitations for the structure and if the construction personnel/ supervisor heed to these limitations. The broad reasons for cracking, etc. are brought out below:

- Inadequate provision of main steel reinforcement, or inadequate provision of temperature reinforcement or wrong spacing of bars, or absence of corner reinforcement may cause unacceptable cracks in concrete.
- One of the most common occurrences is the displacement of top bars in cantilever thin chajjas porches by the movement of concreting gang, causes cracks at the junction point of cantilever chajjas porches.
- There are number of cases where congestion of reinforcement and difficulties in proper compacting of concrete, particularly at junctions of columns and beams, deep beams, the negative reinforcement over T- and L-beams, needs to be taken care of. In the absence of such care, concrete is sure to crack.

2.23 CRACKS DUE TO EXTERNALLY APPLIED LOADS

Load induced tensile stress may result in cracks in concrete elements. A design procedure specifying the use of reinforcing steel, not only to carry tensile forces, but also obtaining both an adequate crack distribution and reasonable limit on crack width is recommended. Flexural and tensile crack widths can be expected to increase with time for members subjected to either sustained or repetitive loading. A well-distributed reinforcing arrangement offers the best protection against undesirable cracking.

2.24 ACCIDENTAL LOADINGS EFFECT

2.24.1 Mechanism

Accidental loadings may be characterized as short duration, and onetime events such as the impact of barge against a lock wall or an earthquake. These loadings can generate stresses higher than the strength of concrete, resulting in localized or general failure. Determination of whether accidental loading caused damage to the concrete requires knowledge of the events preceding discovery of the damage. Usually, the damage caused by accidental loading is easy to diagnose.

2.24.2 Symptoms

Visual inspection shows spalling or cracking of concrete, which has been subjected to accidental loadings.

2.24.3 Prevention

Accidental loadings by their very nature cannot be prevented. Minimizing the effects of some occurrences by following proper design procedures (an example is the design of earthquake resistant structure) or by proper attention to detailing of structure reduces the impacts of accidental loadings.