Unit – II

SERVICEBILITY AND DURABILITY OF CONCRETE

Quality assurance for concrete construction – concrete properties – strength, permeability, thermal properties and cracking. – Effects due to climate, temperature, chemicals, corrosion – design and construction errors – Effects of cover thickness and cracking

Quality assurances for concrete construction

Quality management ensures that every component of the structure keeps performing throughout its life span. In fact, quality is a measure of the degree of excellence and is indeed related to fulfillment enjoyed by the user. In concrete construction, even if rigid quality is not followed, the material performs for a short while without loss of strength. On account of this forgiving property of concrete, many in the construction industry have been operating under the illusion that rigid quality management, which is essential for mechanical industries, is not so important for concrete manufacture. This is not correct. The quality management in the current day context is based on the fact that the probability of failure of structure must be as low as possible and definitely lower than a prefixed accepted limit. Hence, quality management in essence is the management of uncertainties inherent in the construction industry.

Need for Quality Assurance

- All involved with the construction and use of a concrete structure are concerned that the quality is necessary to give good performance and appearance throughout its intended life.
- The client requires it in promoting his next engineering scheme.
- The designer depends on it for his reputation and professional satisfaction.
- The material producer is influenced by the quality 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 considerably complicated by the problems of time scheduling and costs.
- Finally the user is rewarded by a functionally efficient structure of good appearance. It would seem to follow therefore that since all responsible parties gain by quality it should be automatically achieved.
- Yet this is not so, and a considerable positive effort must be employed to achieve it.

- This effort can best be expanded by instituting a quality assurances scheme which involves each of the above parties.

  The quality management system in a true sense should have the following three components

  1) Quality assurance plan(QAP)
  2) Quality control process(QC)
  3) Quality Audit(QA)

  Quality assurance plan

The following aspects should be addressed by any QAP:

- Organizational Set-up
- Responsibilities of personnel
- Coordinating personnel
- Quality control measure
- Control norms and limit
- Acceptance/rejection criteria
- Inspection program
- Sampling, testing and documentation
- Material specification and qualification
- Corrective measure for noncompliance
- Resolution of disputed/difficulties
- Preparation of maintenance record

The quality assurance plan starts right from the planning and design stage itself, and it can be defined as a procedure for selecting a level of quality required for a project.

Quality Control Plan

- It is a system of procedures and standards by which the contractor, the product manufacture and the engineer monitor the properties of the product.
- Generally the contracting agency is responsible for the QC process

- A contractor responsible for quality control incurs a cost for it, which is less than the uncontrolled cost for correcting the defective workmanship or replacing the defective material.
- Hence it is prudent to introduce effective quality control.

2.1.2 Quality Audit

- This is the system of tracing and documentation of quality assurance and quality control program.
- It is the responsibility of the process owner.
- Both design and construction processes comes under this process.
- The concept of QA encompasses the project as a whole.
- Each element of the project comes under the preview of quality audit.

Concrete Properties

Strength

Strength of concrete is one of the most important factors. Concrete is used as a structural element, and all structural uses are associated with its compressive strength. Strength of concrete is defined as the resistance that concrete provides against load so as to avoid failure. It depends on the water-cement ratio, quality of aggregates, compaction, curing etc. The primary factor that affects the strength of concrete is the quality of cement paste, which in turn, depends on the quality of water and cement used.

Sometimes it is economical to add pozzolana or use Portland pozzolana cement instead of ordinary cement concrete. Pozzolanas are materials that have little cementing value but rich with calcium hydroxide to form compounds that are cementitious. This reaction contributes to the ultimate strength and watertightnesss of concrete. Pozzolanas also increases the plasticity and workability of concrete. Excessive addition of pozzolanas affects durability. So it should be used along with cement as a partial replacement or in small percentage.

Generally construction industry needs faster development of strength in concrete so that the projects can be completed in time or before time. This demand is catered by high early strength cement, use of very low W/C ratio through the use of increased cement concrete and reduced water content. But this result in higher thermal shrinkage, drying shrinkage, modulus of elasticity and lower creep coefficients. With higher quantity of cement content, the concrete exhibits greater cracking tendencies because of increase in thermal and during shrinkage. As the creep coefficient is low in such concrete there will not be much slope for relaxation of stresses. Therefore high early strength concretes are more prone to cracking than moderate or low strength concrete.

Of course, the structural cracks in high strength concrete can be controlled by use of sufficient steel reinforcement. But this practice does not help the concrete durability, as provision of more steel reinforcement; will only results in conversion of the bigger cracks to smaller cracks. And these smaller cracks are sufficient to allow oxygen, carbon dioxide and moisture get into the concrete to affect the long term durability of concrete.

Field experience have also corroborated that high early strength concrete are more cracks-prone. According to a recent report, the cracks in pier caps have been attributed to use of high cement content in concrete. Contractors apparently thought that a higher than the desired strength would speed up the construction time, and therefore used high cement content.

Similarly, report submitted by National Cooperative Highway Research Programme(NCHRP) of USA during 1995, based on their survey showed that more than, 100000 concrete bridge decks in USA showed full depth transverse cracks even before structures were less than one month old. The reasons given are that combination of thermal shrinkage and drying shrinkage caused most of the cracks. It is to be noted that deck concrete is made of high strength concrete. These concrete have a high elastic modulus at an early age. Therefore, they develop high stresses for a given temperature change or amount of drying shrinkage. The most important point is that such concrete creeps little to relieve the stresses.

It is interesting to see that the above point of view is not fully convincing when seen from many other consideration.

Firstly, the high strength concrete has high cement content and low water content. On account of low water content, only surface hydration of cement particle will have taken place leaving considerable amount of unhydrated core of cement grains. This unhydrated core of cement grains has strength in reserve. When micro cracks have developed, the unhydrated core gets hydrated, getting moisture through micro cracks. The hydration products so generated seal the cracks and restore the integrity of concrete for long term durability.

Secondly, as per aiticin, the quality of products of hydration formed in the case of low W/C ratio is superior to the quality of gel formed in the case of high W/C ratio.

Thirdly, the micro structure of concrete with low W/C ratio is much stronger and less permeable. The interconnected networks of capillaries are so fine that water cannot flow any more through them. It is reported that when tested for chloride ion permeability, it showed 10-50 times slower penetration than low strength concrete.

Permeability

Concrete is a permeable and a porous material. The rates at which liquids and gases can move in the concrete are determined by its permeability. Permeability affects the way in which concrete resists external attack and the extent to which a concrete structure can be free of leaks. The permeability is much affected by the nature of the pores, both their size and the extent to which they are interconnected. There can therefore be no one measure of porosity which fully describes the way in which the properties of concrete or of hardened cement paste are affected.

If a material were judged, the decision would rest primarily on the choice of medium used for testing.

For (ex) Vulcanized rubber would be found impervious and nonporous if tested with mercury, but if tested with hydrogen it would be found to be highly porous. Early work on the permeability of concrete was generally related to its use in dam construction.

In 1946 Powers and Brownyard examined the permeability of cement pastes and came to the conclusion that well-cured neat paste of low w/c ratio is practically impermeable and that the permeability of cement pastes depends almost entirely on the amount of capillary water present, since the gel pores are extremely small. Earlier work of Ruettgers resulted that the permeability of concrete is generally much higher than the theoretical permeability owing to the fissures under the aggregate that permit the flow partially to bypass the paste and owing to the capillaries in the paste that permit the flow in the paste to bypass the gel. Numerical values for permeability of concrete need to be examined with care.

The coefficient of permeability K1 is obtained from applying Darcy‟s law for low velocity flow,

$$(dr/dt).(1/A)=K1.(\hat{}h/L)$$

dr/dt= The rate of volume flow (m^3s^{-1})

A= Area of porous medium normal to the direction of flow (M^2)

^h= Drop in hydraulic head across the thickness of the medium (m).

L= Thickness of the medium (m).

K1=Coefficient of permeability depending on the properties of the medium and of fluid (ms^{-1})

For any set of tests, the value of K1 depends on both the medium and the fluid and therefore represents the permeability of the medium to a specified fluid at specified temperature. As pointed out by the concrete society working party, a number of factors can account for widespread of permeability results for a specific w/c ratio concrete, due primarily to aspects of the test method for eg:

a) Varying and continuing hydration of the specimen.
b) Incomplete and variable initial saturation.
c) Lack of absolute water cleanliness.
d) Chemical reaction of specimen with the test fluid
e) Effect of dissolved gases where high pressure air is used to pressurize the water.
f) Silting due to movement of fines.
g) Micro structural collapse and macroscopic instability when very high flow pressures are used.
h) Lack of attainment of steady state condition.

The composition of the water and the presence of dissolved materials can also have a substantial effect. The drying was found to increase the permeability and for the particular specimens examined, drying at 79% relative humidity increased the permeability about 70-told. The flow tests are appropriate for testing material which has a high permeability but for concrete of low permeability a method in which the depth of penetration is measured is usually a core practical proposition. The water tightness of a concrete structure is not determined by the permeability of the hardened cement paste or even by the measured permeability of laboratory specimens of the concrete. The permeability of concrete, both to moisture and to gas is important in relation to the protection afforded to embedded steel. The initial surface absorption test measures the rate at which water is absorbed in to the surface of the concrete for a brief period under a head of 200mm. The Figg test subsequent modifications of its measure the permeability of the concrete at the bottom of a fine hole drilled to some depth below the concrete surface. The depth to which water which is absorbed into concrete under little head has been shown to be initially a linear function of the square-root of time. The slope of this function is called Sorptivity. The sorptivity is a measure for assessing the protection that will be a afforded to embedded reinforcing steel, particularly after it has become activated.

Penetration of concrete by materials in solution may adversely affect its durability. For instance, when $Ca(OH)_2$ is being leaching out or an attack by aggressive liquids takes place. This penetration depends o the permeability of the concrete. Since permeability determines the relative ease, with which concrete can become saturated with water, permeability has an important bearing on the vulnerability of concrete to frost. Furthermore, in case of reinforced concrete, the ingress of moisture and of air will result in the corrosion of steel. Since this leads to an increase in the volume of the steel, cracking and spalling of the concrete cover may well follow.

The high permeability of concrete in actual structures is due to the following reasons:

- The large microcracks with generated time in the transition zone.
- Cracks generated through higher structural stresses.
- Due to volume change and cracks produced on account of various minor reasons.
- Existence of entrapped air due to insufficient compaction.

Thermal Properties

Concrete is a material used in all climatic regions for all kinds of structures. Thermal properties are important in structures in which temperature differentials occur including those due to solar radiation during casting and the inherent heat of hydration. Knowledge of thermal expansion is required in long span bridge girders, high rise buildings subjected to variation of temperatures, in calculating thermal strains in chimneys, blast furnace and pressure vessels, in dealing with pavements and construction joints, in dealing with design of concrete dams and in host of other structures where concrete will be subjected to higher temperatures such as fire, subsequent cooling, resulting in cracks, loss of serviceability and durability.

The thermal properties of concrete are more complex than those of most other materials because these are affect ted by moisture content and porosity.

Threee types of tests are commonly used to study the effect of transient high temperature on the stress-strain properties of concrete under compression. These are the following,

(a) Unstreesed Tests: Where specimens are heated under no initial stress and then loaded until the point of failure.

(b) Stressed Tests: Where a fraction of the compressive strength capacity at room temperature is applied and sustained during heating. When the target temperature is reached, the load is increased until the point of failure.

(c) Residual Unstressed Tests: Where the specimens are heated without any load, cooled to room temperature, and then loaded until the point of failure.

To study about the thermal properties of concrete the following properties needs to be known,

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

Thermal Conductivity:

This measures the ability of material to conduct heat. Thermal conductivity is measured in joules per second per square meter of area of body when the temperature deference is 1^0C 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 and 3.4j/m^2s ^{0}c/m.

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.

$$\text{Diffusivity} = \frac{\text{Conductivity}}{\text{CP}}$$

Where C is the specified heat and P is the density of concrete. The range of diffusivity of concrete is between 0.002 to 0.006 m^2/h.

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 and 1170 j/kg per ^{0}C.

Coefficient of thermal expansion:

Coefficient of thermal expansion is defined as the change in 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 $11*10^{-6}$ and $20*10^{-6}$ per ^{0}C. Coefficient of thermal expansion of aggregate varies between $5*10^{-6}$ and $12*10^{-6}$ per ^{0}C. Limestone and gabbors will have low values and quartzite will have high values of coefficient of thermal expansion. Therefore the kind of aggregate and content of aggregate influences the coefficients of thermal expansion of concrete.

Cracking

Plastic shrinkage cracks

Water from fresh concrete can be lost by evaporation, absorption of sub grade, formwork and in hydration process. When the loss of water from the surface of concrete is faster than the migration of water from interior to the surface dries up. This creates moisture gradient which results n surface cracking while concrete is still in plastic condition. The magnitude of plastic shrinkage and plastic shrinkage cracks are depending upon ambient temperature, relative humidity and wind velocity.

Rate of evaporation of water in excess of 1 kg/m^2 per hour is considered critical. In such a situation the following measures could be taken to reduce or eliminate plastic shrinkage cracks.

- Moisten the sub grade and formwork
- Erect temporary wind breakers to reduce the wind velocity over concrete.
- Erect temporary roof to protect concrete from hot sun.

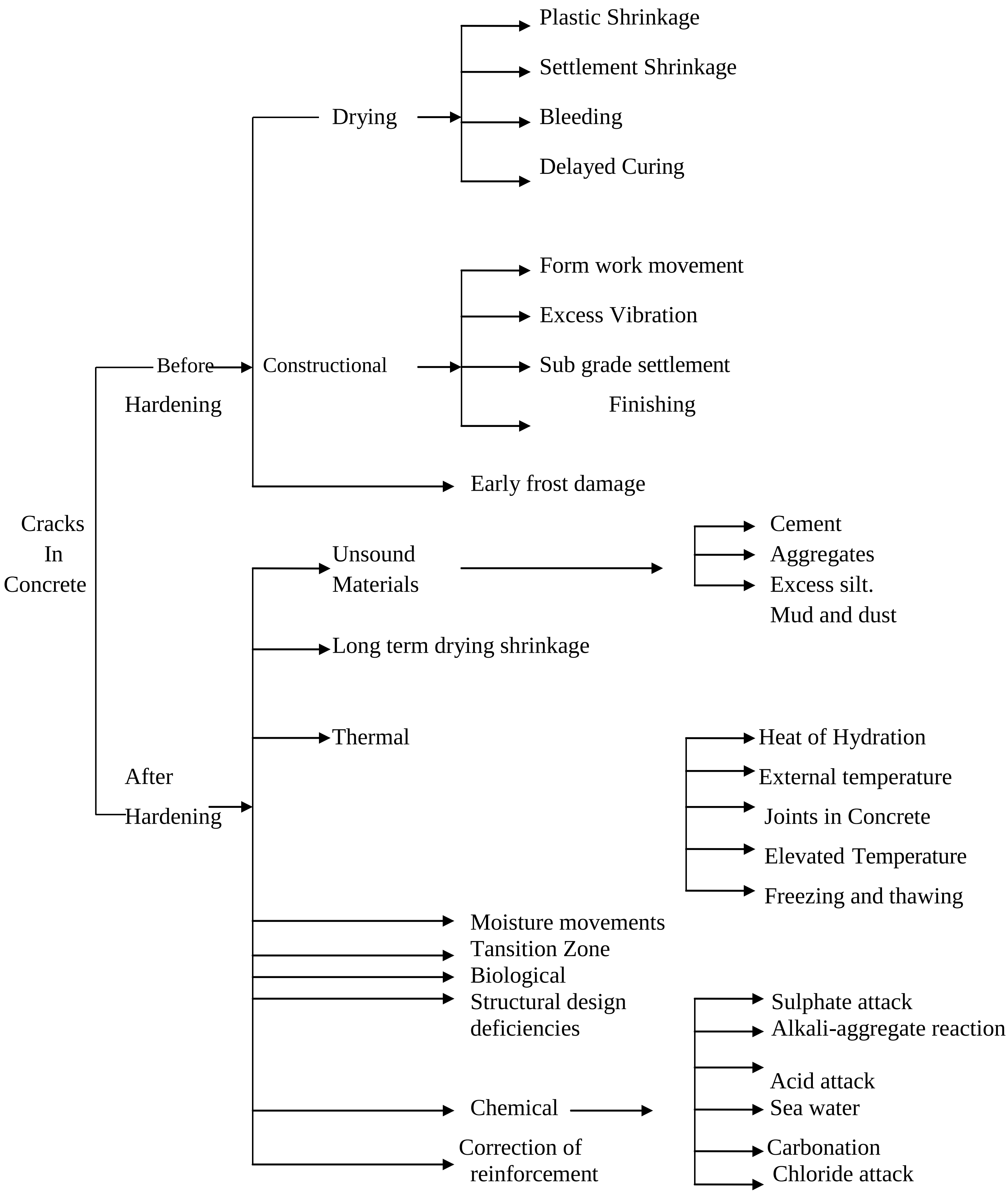

Fig 2.1 Various Types and Causes of cracks in Concrete

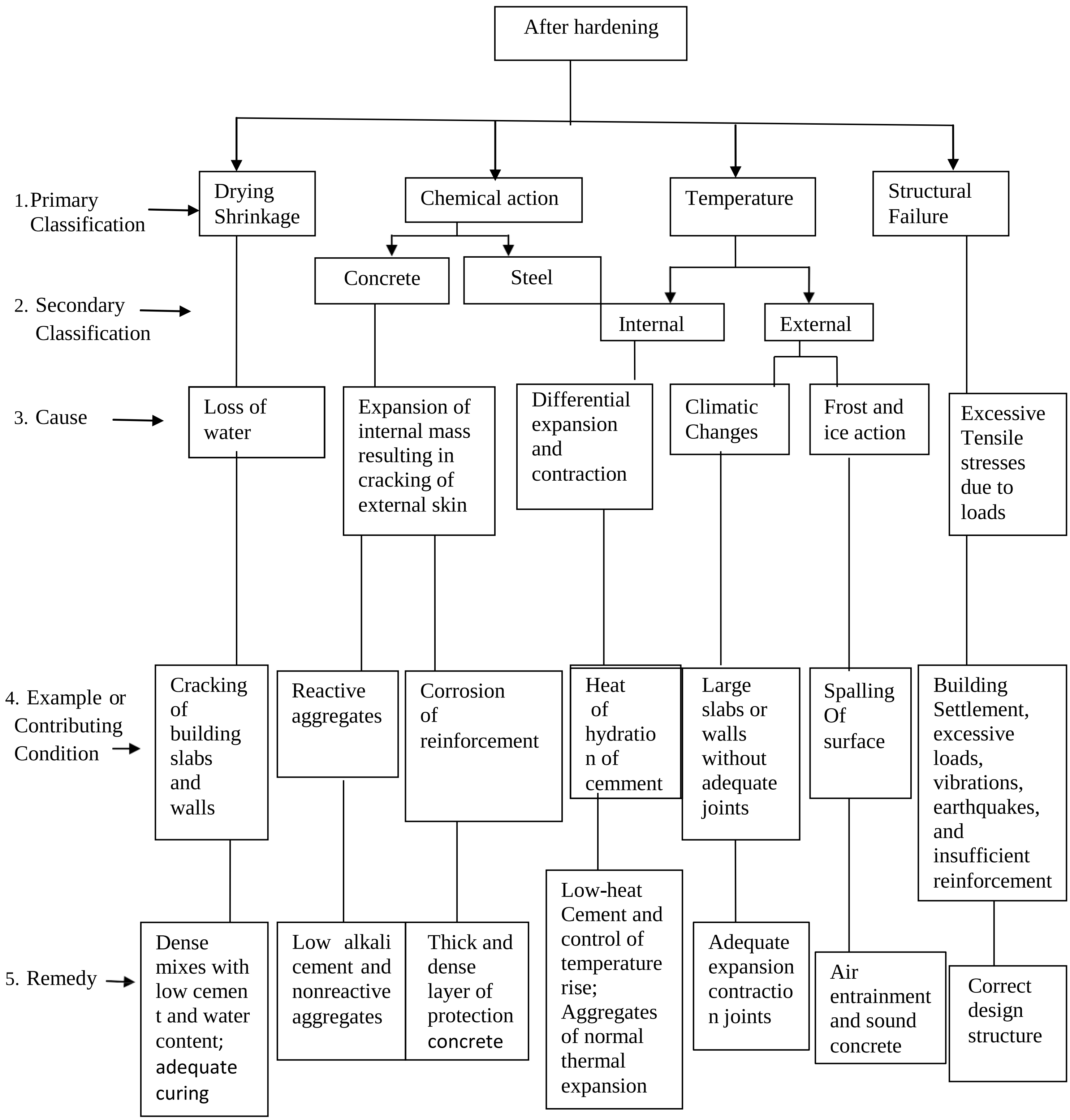

Fig2.3 Other Properties, types and causes of concrete cracking

- Reduce the time between placing and finishing. If there is delay cover the concrete with polyethylene sheets.
- Minimize evaporation by covering concrete with burlap, fog spray and curing compound.

Plastic shrinkage cracks are very common in hot weather conditions in pavements floor and roof slab concrete.

Once they are forms it"s difficult to rectify. In case of prefabricated units, they can be heated by controlled revibration, if the concrete is in plastic condition. In roof and floor slab it is difficult to repair. However, sometimes, thick sluury is poured over the cracks and well worked by trowel after striking each side of the cracks to seal the same. The best way is to take all precautions to prevent evaporation of water from the wet concrete, finish it fast, and cure it as early as feasible.

In Mumbai – Pune express highway, the fresh concrete is protected by 100 meter long low tenterected on wheel to break the wind and also to protect the green concrete from hot sun. In addition curing compound is sprayed immediately after finishing operations.

Plastic shrinkage cracks, if care is not taken, will affect the durability of concrete in many ways.

Settlement Cracks

If the concrete is free to settle uniformly, then there is no crack. If there is any obstruction to uniform settlement by way of reinforcement or larger piece of aggregate, then it creates some voids or cracks. This is called settlement cracks. This generally happens in a deep beam.

Concrete should be poured in layers and each layer should be properly compacted. Building up of large quantity of concrete over a beam should be avoided.

Sometimes, the settlement cracks and voids are so severe it needs grouting operators to seal them off. Revibration, if possible is an effective step. Otherwise they affect the structural integrity of the beam or any other member and badly affect the durability.

Bleeding

Shrinkage of concrete is one of the important factors contributing to lack of durability of concrete. Shrinkage is mainly responsible for causing cracks of larger magnitude or minor micro cracks. The aspect of cracking in concrete is very complex, involving many factors such as magnitude of shrinkage, degree of restraint, extensibility of concrete, extent of stress relaxation by creep and at what age the shrinkage is appearing etc. Cracks can be avoided only if the stress induced by shrinkage strain, after relaxation by creep, is at all time less than the tensile strength of concrete. The above situation is not happening in most of the cases and as such generally shrinkage causes cracks in concrete.

Durability:

Definition:

Durability of concrete may be defined as the ability of concrete to resist weathering action, chemical attack, and abrasion while maintaining its desired engineering properties. Different concretes require different degrees of durability depending on the exposures environment and properties desired.

For example, concrete exposed to tidal seawater will have different requirements than an indoor concrete floor. Concrete ingredients, their proportioning, interactions between them, placing and curing practices, and the service environment determine the ultimate durability and life of concrete.

Some important degradation mechanisms in concrete structures include the following:

1. Freeze-thaw damage (physical effects, weathering).
2. Alkali-aggregate reactions (chemical effects).
3. Sulphate attack(chemical effects).
4. Microbiological induced attack(chemical effects).
5. Corrosion of reinforcing steel embedded in concrete (chemical effects).
   a)carbonation of concrete
   b) chloride induced.
6. Abrasion (physical effects).
7. Mechanical loads(physical effects).

Effect of freezing and thawing:

- The most severe climate attack on concrete occurs when concrete containing moisture is subjected to cycles of freezing and thawing.
- The capillary pores in the cement are of such a size that water in them will freeze when the ambient temperatures is below 0^0C.

- The gel pores are so small that water in them does not 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 distance.
- 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 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 lost moisture as the concrete dries.
- Fully saturated concrete, if permanently submerged, will not need protection against freezing, but concrete which as been saturated and is exposed to freezing, as for example in the tidal range, may not be effectively protected by air-entrainment.

Effect of Temperature:

- The temperature difference within a concrete structure, result in differential volume change.
- When the tensile strain due to differential volume change exceeds the tensile strain capacity of concrete, it will crack.
- The temperature differentials associated with the hydration of cement, affect the mass concrete such as in large columns, piers, footings, dams etc. Whereas the temperature differentials due to changes in the ambient temperature can affect the whole structure.
- The liberation of the heat of hydration of cement causes the internal temperature of concrete to rise during the initial curing period, so that is is usually slightly warmer than its surroundings.
- In thick sections and with rich mixes the temperature differential may be considerable. As the concrete cools it will try to contract.

- Any restraint on the free contraction during cooling will result in tensile stresses which are proportional to the temperature change, coefficient of thermal expansion, effective modulus of elasticity and degree of restraint.
- The more massive the structure, the greater is the potential for temperature differential and degree of restraint.
- Thermally induced cracking can be reduced by controlling the maximum internal temperature, delaying the onset of cooling by insulating the formwork and exposed surfaces, controlling the rate of cooling, and increasing the tensile strain capacity of the concrete.
- Special precautions need to be taken in the desing of structures in which some portions are exposed to temperature changes while the other portions of structures are either partially or completely protected.
- A drop in temperature may result in the cracking of the exposed element while increase in temperature may cause cracking in the protected portion of the strcture.
- Temperature gradients cause deflection and rotation in structural members; if these are restrained serious stresses can result.
- Allowing for movement by using properly designed contraction joints and correct detailing will help alleviate these problems. If the cracks do form.
- Remedial measures are similar to those for cracks that form after a structure in service.

Effect of chemical:

- The most important constituent of concrete namely cement is alkaline; so it will react with acids or acidic compounds in presence of moisture, and in consequence the matrix becomes weakened and its constituents may be leached out. The concrete may crack, as a result of expansive reactions between aggregate containing active silica and alkalies derived from cement hydration, admixture or external sources(e.g. curing water, ground water, alkaline solutions stored). The alkali – silica reaction results in the formation of a swelling gel, which tends to draw water from other portions of concrete. This causes local expansion nd accompanying tensile stresses which if large may eventually result in the complete deterioration of the structure. Control measures include proper selection of aggregate, use of low-alkali cement and use of pozzolana. Typical symptoms in unreinforced and highly reinforced concrete are *map cracking*, usually in a rough hexagonal mesh pattern and gel excluding from cracks.

- The alkali-carbonate reactions occurs with certain limestone aggregate and usually results in the formation of alkali-silica product between aggregate particiles and the surrounding cement paste. The problem may be minimized by avoiding reactive aggregate, use of smaller size aggregate and use of low-alkali cement.
- When the sulphate bearing waters come in contact with the concrete, the sulphate penetrates the hydrated paste and reacts with hydrated calcium aluminate to form calcium suphoaluminate with a subsequent large increase in volume, resulting in high tensile stresses causing the deterioration of concrete. The blended or pozzolana cements impart additional resistance to sulphate attacks.
- The calcium hydroxide in hydrated cement paste will combine with carbon dioxide in the air to form calcium carbonate which occupies smaller volume tan the calcium hydroxide resulting called *carbonation shrinkage*. This situation may result in significant surface grazing and ay be especially serious on freshly placed concrete surface kept warm during winter by improperly vented combustion heaters.

Factors which increase concrete vulnerability to external chemical attacks are,

1. High porosity
2. High permeability and absorption resulting from too high W/C ratio.
3. Unsatisfactory grading of aggregate.
4. Cement compaction.
5. Improper choice of cement type for condition of exposure.
6. Inadequate curing period.
7. Exposure to alternate cycles of wetting and drying and to the lesser extended of heating and cooling.
8. Increased fluid velocity which may bring about both replenishment of the aggressive species and increases in the rate of leaching.
9. Suction forces which may caused by drying on one or more faces of a section.
10. Unsatisfactory choice of shape and surface to volume ratio of concrete structure.

Effect of Corrosion:

Formation of white patches

CO_2 reacts with $Ca(OH)_2$ in the cement paste to form $CaCO_3$. The free movement of water carries the unstable $CaCO_3$ towards the surface and forms white patches. It indicates the occurrences of carbonation.

Brown patches along reinforcement

When reinforcement starts corroding, a layer a ferric oxide is formed. This brown product resulting from corrosion may permeate along with moisture to the concrete surface without cracking of the concrete.

Occurrence of cracks

The increase in volume exerts considerable bursting pressure on the surrounding concrete resulting in cracking. The hair line crack in the concrete surface lying directly above the reinforcement and running parallel to it is the positive visible indication that reinforcement is corroding. These cracks indicate that the expanding rust had grown enough to split the concrete.

Formation of multiple cracks

As corrosion progresses, formation of multiple layers of rust on the reinforcement which in turn exert considerable pressure on the surrounding concrete resulting in widening of hair cracks. In addition, a number of new hair cracks are also formed. The bond between concrete and the reinforcement is considerably reduced. There will be a hollow sound when the concrete is tapped at the surface with a light hammer.

Snapping of bars

The continued reduction in the size of bars results in snapping of the bars. This will occur in ties/stirrups first. At this stage, size of the main bars is reduced.

Buckling of bars and bulging of concrete

The spalling of the cover concrete and snapping of ties causes the main bars to buckle. This results in bulging of concrete in that region. This follows collapse of the structure. When corrosion of reinforcement starts, the deterioration is usually slow but advances in geometrical progression. Corrosion can also cause structural failure due to reduced C/S and hence reduced load carrying capacity. It is possible to arrest the process of corrosion at any stage by altering the corrosive environment in the vicinity of the reinforcement.

Design Errors and Construction Errors:

Design Errors

Design errors may be divided into two general types:

1. Those resulting from inadequate structural design
2. Those resulting from lack of attention to relatively minor design details.

Each of the two types of design errors is discussed below.

(1) Inadequate structural design.

(a) Mechanism. The failure mechanism is simple – the concrete is exposed to greater stress than it is capable of carrying or it sustains greater strain than its strain capacity.

(b) Symptoms. Visual examinations of failures resulting from inadequate structural design will usually show one of two symptoms.

1. First, errors in design resulting in excessively high compressive stresses will result in spalling. Similarly, high torsion or shear stresses may also result in spalling or cracking.
2. Second, high tensile stresses will result in cracking.

To identify inadequate design as a cause of damage, the locations of the damage should be compared to the types of stresses that should be present in the concrete. For example, if spalls are present on the underside of a simple-supported beam, high compressive stresses are not present and inadequate design may be eliminated as a cause. However, if the type and location of the damage and the probable stress are in agreement, a detailed stress analysis will be required to determine whether inadequate design is the cause. Laboratory analysis is generally not applicable in the case of suspected inadequate design. However, for rehabilitation projects, thorough petro graphic analysis and strength testing of concrete from elements to be reused will be necessary.

(c) Prevention.

Inadequate design in prevented by thorough and careful review of all design calculations. Any rehabilitation method that makes use of existing concrete structural members must be carefully reviewed.

(2) Poor design details

A structure may be adequately designed to meet loadings and other overall requirements, poor detailing may result in localized concentrations of high stresses in otherwise satisfactory concrete. These high stresses may result in cracking that allows water or chemicals access to the concrete. In other cases, poor design detailing may simply allow water to pond on a structure, resulting in saturated concrete. In general, poor detailing does not lead directly to concrete failure; rather, it contributes to the action of one of the other causes of concrete deterioration described in this chapter. Several specific types of poor detailing and their possible effects on a structure are described in the following paragraphs. In general, all of these problems can be prevented by a thorough and careful review of plans and specifications for the project. In the case of existing structures, problems resulting from poor detailing should be handled by correcting the detailing and not by simply responding to the symptoms.

(a) Abrupt changes in section.

Abrupt changes n section may cause stress concentrations that may result in cracking. Typical examples would include the use of relatively thin sections such as bridge decks rigidly tied into massive abutments or patches and replacement concrete that are not uniform in plan dimensions.

(b) Insufficient reinforcement at reentrant corners and openings.

Reentrant corners and openings also tend to cause stress concentrations that may cause cracking. In this case, the best prevention is to provide additional reinforcement in areas where stress concentrations are expected to occur.

(c) Inadequate provision for deflection.

Deflection in excess of those anticipated may result in loading of members or sections beyond the capacities for which they were designed. Typically, these loadings will be induced in walls or partitions, resulting in cracking.

(d) Inadequate provision for drainage.

Poor attention to the details of draining a structure may result in the ponding of water. This ponding may result in leakage or saturation of concrete. Leakage may result in damage to the interior of the structure or in staining and encrustations on the structure. Saturation may result in severely damaged concrete if the structure is in an area that is subjected to freezing and thawing.

(e) Insufficient travel in expansion joints.

Inadequately designed expansion joints may result in spalling of concrete adjacent to the joints. The full range of possible temperature differentials that a concrete may be expected to experience should be taken into account in the specification for expansion joints. There is no single expansion joint that will work for all cases of temperature differential.

(f) Incompatibility of materials.

The use of materials with different properties (modulus of elasticity or coefficient of thermal expansion) adjacent to one another may result in cracking or spalling as the structure is loaded or as it is subjected to daily or annual temperature variations.

(g) Neglect of creep effect.

Neglect of creep may have similar effects as noted earlier for inadequate provision for deflections. Additionally, neglect of creep in prestressed concrete members may lead to excessive prestress loss that in turn results in cracking as loads are applied.

(h) Rigid joints between precast units.

Designs utilizing precast elements must provide for movement between adjacent precast elements or between the precast elements and the supporting frame. Failure to provide for this movement can result in cracking or spalling.

(i) Unanticipated shear stresses in piers, columns, or abutments.

Through lack of maintenance, expansion bearing assembles are allowed to become frozen, horizon-tal loading may be transferred to the concrete elements supporting the bearings. The result will be cracking in the concrete, usually compounded by other problems which will be caused by the entry of water into the concrete.

Construction Errors:

Failure to follow specified procedures and good practice or outright carelessness may lead to a number of conditions that may be grouped together as construction errors. Most of these errors do not lead directly to failure or deterioration of concrete. Instead, they enhance the adverse impacts of other mechanisms. Each error will be briefly described along with preventative methods. In general, the best preventive measure is a thorough knowledge of what these construction errors are, plus an aggressive inspection program. It should be noted that errors of the type described in this section are equally as likely to occur during repair or rehabilitation projects as they are likely to occur during new construction.

(a) Adding water to concrete. Water is usually added to concrete in one or both of the following circumstances:

1. First, water is added to the concrete in a delivery truck to increase slump and decrease emplacement effort. This practice will generally lead to concrete with lowered strength

and reduced durability. As the w/c of the concrete increases, the strength and durability will decrease.

2. In the second case, water is commonly added during finishing of flatwork. This practice leads to scaling, crazing, and dusting of the concrete in service.

(b) Improper alignment of formwork.

Improper alignment of the formwork will lead to discontinuities on the surface of the concrete. While these discontinuities are unsightly in all circumstances, their occurrence may be more critical in areas that are subjected to high-velocity flow of water, where cavitations erosion may be induced, or in lock chambers where the “rubbing” surfaces must be straight.

(c) Improper consolidation.

Improper consolidation of concrete may result in a variety of defects, the most common being bugholes, honeycombing, and cold joints.

“Bugholes” are formed when small pockets of air or water are trapped against the forms. A change in the mixture to make it less “sticky” or the use of small vibrators worked near the form has been used to help eliminate bugholes.

Honeycombing can be reduced by inserting the vibrator more frequently, inserting the vibrator as close as possible to the form face without touching the form, and slower withdrawal of the vibrator. Obviously, all of these defects make it much easier for any damage-causing mechanism to initiate deterioration of the concrete.

Frequently, a fear of “overconsolidation” is used to justify a lack of effort in consolidating concrete. Overconsolidation is usually defined as a situation in which the consolidation effort causes all of the coarse aggregate to settle to the bottom while the paste rises to the surface. If this situation occurs, it is reasonable to conclude that there is a problem of a poorly proportioned concrete rather than too much consolidation.

(d) Improper curing.

Curing is probably the most abused aspect of the concrete construction process. Unless concrete is given adequate time to cure at a proper humidity and temperature, it will not develop the characteristics that are expected and that are necessary to pro-vide durability. Symptoms of improperly cured concrete can include various types of cracking and surface disintegration. In extreme cases where poor curing leads to failure to achieve anticipated concrete strengths, structural cracking may occur.

(e) Improper location of reinforcing steel.

This section refers to reinforcing steel that is improperly located or is not adequately secured in the proper location. Either of these faults may lead to two general types of problems.

1. First, the steel may not function structurally as intended, resulting in structural cracking or failure. A particularly prevalent example is the placement of welded wire mesh in floor slabs. In many case, the mesh ends up on the bottom of the slab which will subsequently crack because the steel is not in the proper location.

2. The second type of problem stemming from improperly located or tied reinforcing steel is one of durability. The tendency seems to be for the steel to end up near the surface of the concrete. As the concrete cover over the steel is reduced, it is much easier for corrosion to begin.

(f) Movement of formwork

Movement of formwork during the period while the concrete is going from fluid to a rigid material may induce cracking and separation within the concrete. A crack open to the surface will allow access of water to the interior of the concrete. An internal void may give rise to freezing or corrosion problems if the void becomes saturated.

(g) Premature removal of shores or reshores.

If shores or reshores are removed too soon, the concrete affected may become overstressed and cracked. In extreme cases there may be major failures.

(h) Settling of the concrete.

During the period between placing and initial setting of the concrete, the heavier components of the concrete will settle under the influence of gravity. This situation may be aggravated by the use of highly fluid concretes. If any restraint tends to prevent this settling, cracking or separations may result. These cracks or separations may also develop problems of corrosion or freezing if saturated.

(i) Settling of subgrade.

If there is any settling of the subgrade during the period after the concrete begins to become rigid but before it gains enough strength to support its own weight, cracking may also occur.

(j) Vibration of freshly placed concrete.

Most construction sites are subjected to vibration from various sources, such as blasting, pile driving, and form the operation of construction equipment.

Freshly placed concrete is vulnerable to weakening of its properties if subjected to forces which disrupt the concrete matrix during setting.

(k) Improper finishing of flat work.

The most common improper finishing procedures which are detrimental to the durability of flat work are discussed below.

(1) Adding water to the surface. Evidence that water is being added to the surface is the presence of a large paint brush, along with other finishing tools. The brush is dipped in water and water is “slung” onto the surface being finished.

(2) Timing and finishing. Final finishing operations must be done after the concrete has taken its initial set and bleeding has stopped. The waiting period depends on the amouts of water, cement, and admixtures in the mixture but primarily on the temperatures of the concrete surface. On a partially shaded slab, the part in the sun will usually be ready to finish before the part in the shade.

(3) Adding cement to the surface. This practice is often done to dry up bleed water to allow finishing to proceed and will result in a thin cement-rich coating which will craze or flake off easily.

Effect of Cover Thickness

There is a substantial experience which relates durability and the amount of water. The thicker the cover over the steel is, the longer it will take the chloride ions to reach the steel and reduce the pH and passivity provided by the cement. However, excessive cover can led to the development of a few wide cracks under overstress, whereas a thinner cover results in many small cracks.

As opposed to the above mentioned facts, which appear to justify the rigid rules on cover, are the fallowing facts.

- Ships built during World War I and II had covers of only about 20mm, yet they did not suffer corrosion steel.
- In the erstwhile USSR, many floating dry-docks have been built with covers of 15 and 20mm with highly successful durability over many years of adverse exposure.

It is confirmed opinion that the impermeability of the cover is of major importance. The thickness should be related to the steel bar diameter and the maximum size of the coarse aggregate.

The general factors affecting permeability, such as cement content, water/cement ratio, compaction and consolidation of the concrete, and curing are important. While many fee that prestressing steel should have a greater cover than non-stressed steel, because of the more serious consequences of corrosion. Prestressed concrete pilling by hundreds of thousands are rendering completely successful service with only 4-6cm of cover. Other factors affecting cover are the tolerances of placement of steel and forms, and the depths of honeycombs and bug holes and other surface defects.

Lack of adequate cover contributes much to corrosion in an aggressive environment. A well compacted and continuous, even if thin, cover of good quality concrete on reinforcement is sufficient to protect it from corrosion. The following are the reinforcement thickness of covers for various levels of exposure.

- For normal exposure : At least 50mm thickness •
  For moderate exposure : At least 40mm thickness •
  For mild exposure : At least 30mm thickness
- For normal exposure : At least 20mm thickness

Cover Meter

When a metallic object is placed in the varying magnetic field of coil, the field induces eddy currents in the object. These eddy currents in turn produce an additional magnetic field in the vicinity of the magnetic object. A magnetic field gets superimposed and the magnetic field near the coil also gets modified in the presence of metal. This modification has the same effect as would be obtained if the characteristic of the coil itself had been changed. The change depends upon the electrical conductivity, dimension, magnetic permeability, presence of discontinuity such as crack, frequency of the field of the coil, size and shape of the coil, and the distance of the coil from the metallic object.

It is possible to measure the cover thickness for a known diameter by keeping all other parameters constant. By placing the soil at two different distances from the rebar, both the cover thickness and the diameter of the rebar can be found.

Effect of Cracking

The formation of cracks is dangerous for protection against corrosion. Once concrete cracks, the external depassivating agents can penetrate deep into concrete and set off the process of corrosion. Cracks running transversely to the reinforcement are less harmful than the longitudinal cracks along the reinforcement.

Thus in the order to induce the process of corrosion and to keep it going, at least one of the following conditions must exist in any RC structure.

- Chloride ion concentration in excess of the threshold value at the interface of the reinforcement and concrete or sufficient advancement of the carbonation front to destroy the passivity of the ferric oxide surface layer of the reinforcement.
- Adequate moisture in the concrete to facilitate the movement of chloride ions and provide a conduction path between the anodic and the cathodic areas on the steel.
- Sufficient oxygen supply to the cathodic areas in order to maintain such areas in a depolarized condition.
- Difference in electrochemical potentials at the surface of the reinforcement.
- Low values of electrical resistivity of concrete.
- Relative humidity in the range 50-70%.
- Higher ambient temperature.