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CAUSES OF CONCRETE FAILURE

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ABSTRACT

Concrete and steel are materials commonly used in building construction. Concrete is formed by mixture of aggregates which are sand and stone, and bonded together by water and cement with proper ratio. Steel is a material that is manufactured under carefully controlled condition by which its properties are determined in a laboratory. Combining concrete and steel gives increased strength to resist heavy loads to increase the lifetime of the structure. Even though concrete and steel give many advantages on building, they can also cause failure to the structure because of the impropriate procedure work, and lacks of efficient control and monitoring mechanism. The exceptional durability of portland cement concrete is a major reason why it is the world's most widely used construction material. But material limitations, design and construction practices, and severe exposure conditions can cause concrete to deteriorate, which may result in aesthetic, functional, or structural problems. Concrete can deteriorate for a variety of reasons, and concrete damage is often the result of a combination of factors. The authors made an attempt to review the potential causes of concrete deterioration and the factors that influence them Corrosion of reinforcing steel and other embedded metals is the leading cause of deterioration in concrete. When steel corrodes, the resulting rust occupies a greater volume than the steel. This expansion creates tensile stresses in the concrete, which can eventually cause cracking, delamination, and spalling.

Keywords: Civil Engineering, Cement concrete, Corrosion, Steel, Portland cement

I. INTRODUCTION

Concrete is one of most durable manmade materials, but even this old industry workhorse has its weaknesses. Exposure to harsh weather, reactions with common elements, and poor construction can all lead to concrete failure.

Concrete degradation may have various causes. Concrete can be damaged by fire, aggregate expansion, sea water effects, bacterial corrosion, calcium leaching, physical damage and chemical damage (from carbonatation, chlorides, sulfates and distilled water). This process adversely affects concrete exposed to these damaging stimuli.

Corrosion is not the only source of failure. Many other sources cause deterioration on reinforced concrete structures; this must be kept in mind and understood well when an inspection is undertaken. These sources of failure include:

- Unsuitable materials
- Unsound aggregate
- Reactive aggregate

- Contaminated aggregate
- Using the wrong type of cement
- Cement manufacturer error
- Contaminated aggregate
- Using the wrong type of cement
- Cement manufacturer error
- Wrong type of admixture
- Substandard admixture
- Contaminated admixture
- Organically contaminated water
- Chemically contaminated water
- Wrong kind of reinforcement
- Size error of steel bars
- Improper workmanship
- Faulty design
- Incorrect concrete mixture (low or high cement content and incorrect admixture dosage)
- Unstable formwork
- Misplaced reinforcement
- Error in handling and placing concrete (segregation, bad placing, and inadequate compacting)
- curing incomplete
- Environmental factors
- Soil alkali
- Seawater or sewage
- Acid industry
- freezing and thawing
- Structural factors
- Load exceeding design
- Accident as ballast load or dropped object
- Earthquake load

II. TYPES OF CRACKS IN CONCRETE AND TYPICAL CAUSES

Cracks can be broadly classified as either active or dormant. If they are active, they show some movement in direction, width or depth over a measured period of time. If the cracks are dormant, they remain unchanged. Some dormant cracks are of no danger, but if left unrepaired, cracks provide channels for moisture penetration, which can lead to future damage. For guidance onv patching dormant cracks,

- Cracks can be more specifically classified based on three factors: 1) direction, 2) width, and 3) depth of the crack. They may be longitudinal, transverse, vertical, diagonal or random. They may range in size from less than 1 mm (fine) to between 1 and 2 mm (medium) to over 2 mm (wide).

The following are some cracks classifications and a brief description.

- Pattern Cracking: Fine openings in regular pattern usually due to inconsistent volume of concrete which is lower near the surface.
- Checking: Shallow openings, closely and irregularly spaced. Hairline Cracking: Small cracks, randomly placed, in exposed areas.
- D-Cracking: Fine cracks at close intervals in a progressive random pattern.
- Cracks can occur in hardened or unhardened concrete and may be caused by some of the following conditions:
- Shrinkage cracking: A crack that occurs only in unhardened concrete. It is often seen as relatively straight lines running parallel with the span of the floor.
- Plastic cracking: A type of shrinkage crack that also only occurs in unhardened concrete. It is seen as diagonal lines in the top of a slab. It is often caused by rapid drying of the surface due to delays in applying the curing membrane.
- Settlement cracking: Caused by local restraining of unhardened concrete around reinforcement or some other obstruction.
- Structural cracking: Usually a result of corrosion of the reinforcing steel or structural over stressing.
- Tension cracking: Only occurs in reinforced concrete and is caused by elongation of the reinforcement in tension zones. It is sometimes seen around columns in flat slabs and on beam soffits near the middle of a span.
- Rust cracking: The most common and most serious cause of structural cracking caused by inadequate reinforcement cover. It gradually develops at varying rates over time depending upon the degree of protection offered by the concrete cover.
- Thermally-induced cracking: Results from stresses produced by temperature changes.

III. CONCRETE DURABILITY PROBLEMS IN STRUCTURES

Concrete durability problems in structures can be due to environment to which the concrete structure is exposure or due to internal causes within the concrete.

The following conditions cause the concrete durability problems in structures:

- Temperature
- Moisture
- Physical factors
- Chemical factors
- Biological factors

Durability of concrete in structure occurs due to above factors which cause weathering in concrete, abrasion or chemical reaction with concrete or reinforcement.

Durability problems in concrete structures related to environmental causes include the following: steel corrosion, delamination, cracking, *carbonation*, sulphate attack, chemical attack, scaling, spalling, abrasion and cavitations.

IV. DURABILITY PROBLEMS DUE TO TEMPERATURE

Concrete contracts and expands due to change in temperature. Concrete expands when temperature increase and contracts when temperature decreases. The effect of these expansion and contraction will not be in unrestrained concrete member. But when a concrete is restrained by connecting members such as columns, beams, slabs, foundations etc, these changes produces significant stresses in concrete which lead to development of cracks.

V. WARPING OF CONCRETE DUE TO TEMPERATURE CHANGE

Concrete exposed to temperatures greater than 95°C (203°F) can have significant effects. These effects are caused due to change in volume of cement paste and aggregates. Cement paste shrinks at high temperature due to dehydration while aggregates expands. The net result of high temperature on concrete is expansion. Therefore, exposure to very high temperatures (i.e. fire) will result in concrete spalling, particularly when the concrete is exposed to high temperatures for a long time.

Factors such as moisture condition of concrete, types of aggregates and their stability, cement content, duration of exposure to high temperature, rate of change in temperature, age of concrete and support conditions etc affects the durability of concrete at high temperature.

VI. CONCRETE DURABILITY PROBLEMS DUE TO MOISTURE

Concrete expands or swells due to increase in moisture and contracts when moisture reduces. These changes in moisture in concrete cause it to swell and shrink. When concrete starts to dry, shrinkage first occurs at the surface of concrete. This shrinkage of concrete at the surface will develop tensile stresses on concrete surface which leads to cracks. If a section of the concrete is restrained, and if concrete joints are not provided, major random cracks may develop.

Shrinkage of reinforced concrete is less than the shrinkage of plain concrete. The difference depends on the amount of reinforcing steel used. Steel reinforcement restricts but does not prevent drying shrinkage. The concrete will crack if the shrinkage strain of the concrete exceeds the limiting tensile strain of the concrete.

VII. PROBLEMS IN CONCRETE DUE TO MOISTURE

The three main problems with moisture and concrete are as follows:

- Carbonation
- The moisture cycle
- Contaminants

VIII. PHYSICAL FACTORS AFFECTING CONCRETE DURABILITY

Many times with the age of concrete, concrete surface is subjected to wear due to sliding, impact, scraping etc. In case of hydraulic structures, the action of the abrasive materials carried by flowing water generally leads to erosion of the concrete. Another cause of damage to concrete in flowing water is cavitation .

Abrasion in concrete is caused by the sliding or scraping of equipment across the concrete. Abrasion damage to concrete may also be caused by subjecting the concrete to abrasive materials (such as sand) that are carried by wind or water.

Tests on concrete results indicate the following facts:

- That abrasion resistance is clearly related to the compressive strength of the concrete.
- Strong concrete has more resistance than weak concrete.
- Since compressive strength depends on the water-cement ratio and adequate curing, a low water-cement ratio and proper curing of the concrete are necessary for abrasion resistance.
- Hard aggregates are more abrasion resistant than soft aggregates.
- Steel-trowelled surfaces resist abrasion more than a surface that is not trowelled.

Cavitations in concrete occurs when a high-velocity, flow of water (or any other fluid) suffers an abrupt change in direction or velocity.

IX. BIOLOGICAL FACTORS AFFECTING DURABILITY

Concrete may be damaged by live organisms such as plants, sponges, boring shells, or marine borers. Rotting seaweed has been known to produce sulfur. Sulfur can be easily converted to sulfuric acid. The presence of sulfuric acid on concrete leads to concrete disintegration.

X. CHEMICAL FACTORS AFFECTING CONCRETE DURABILITY

Durability of concrete is affected by chemical reaction due to chemical interactions between aggressive agents present in the external environment and the constituents of the cement paste. Among the exceptions are alkali-aggregate reactions which occur between the alkalies in cement paste and certain reactive materials when present in aggregate, delayed hydration of crystalline CaO and MgO if present in excessive amounts in Portland cement, and electrochemical corrosion of embedded steel in concrete.

Chemical reactions in concrete results into increase in porosity and permeability, decrease in strength, and cracking and spalling. Sulfate attack, alkali-aggregate attack, and corrosion of embedded steel etc due to chemical reactions in concrete are responsible for deterioration of a large number of concrete structures. Concrete structures in coastal and offshore structures are exposed to chemical and physical processes of deterioration, which aptly demonstrate the complexities of concrete durability problems in practice.

Salt in the surrounding ground, ground water, or air diffuses into the concrete. Steel corrosion results in an increase in the volume of the corroded portion of the reinforcing steel bar. This increase in steel volume causes the concrete to crack and to disintegrate.

XI. FACTORS AFFECTING WORKABILITY OF CONCRETE

Each and every process and materials involved in concrete mixing affects the workability of concrete. Workability of concrete is measured in terms of ease with which it can be mixed, transported to construction site, placed in forms and compacted. It is easy to work with a highly workable concrete as it can be easily mixed, transported, placed and compacted.

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Workability and strength of concrete are inversely proportional. When workability of normal concrete increases, the strength of concrete decreases which affects the durability of concrete.

Factors which affect workability of concrete are:

- Cement content of concrete
- Water content of concrete
- Mix proportions of concrete
- Size of aggregates
- Shape of aggregates
- Grading of aggregates
- Surface texture of aggregates
- Use of admixtures in concrete
- Use of supplementary cementitious materials

The primary materials of concrete are cement, fine aggregates (sand), coarse aggregates and water. Many times admixtures are used in concrete to enhance its properties. Therefore, properties of these materials and their content affect the workability of concrete. Following are the general factors affecting concrete workability:

XII. CEMENT CONTENT OF CONCRETE

Cement content affects the workability of concrete in good measure. More the quantity of cement, the more will be the paste available to coat the surface of aggregates and fill the voids between them. This will help to reduce the friction between aggregates and smooth movement of aggregates during mixing, transporting, placing and compacting of concrete. Also, for a given water-cement ratio, the increase in the cement content will also increase the water content per unit volume of concrete increasing the workability of concrete. Thus increase in cement content of concrete also increases the workability of concrete.

XIII. TYPE AND COMPOSITION OF CEMENT

There are also effect of type of cement or characteristics of cement on the workability of concrete. The cement with increase in fineness will require more water for same workability than the comparatively less fine cement. The water demand increased for cement with high Al_2O_3 or C_2S contents.

XIV. WATER / CEMENT RATIO OR WATER CONTENT OF CONCRETE

Water/cement ratio is one of the most important factor which influence the concrete workability. Generally, a water cement ratio of 0.45 to 0.6 is used for good workable concrete without the use of any admixture. Higher the water/cement ratio, higher will be the water content per volume of concrete and concrete will be more workable.

Higher water/cement ratio is generally used for manual concrete mixing to make the mixing process easier. For machine mixing, the water/cement ratio can be reduced. These generalised method of using water content per volume of concrete is used only for nominal mixes. For designed mix concrete, the strength and durability of concrete is of utmost importance and hence water cement ratio is mentioned with the design. Generally designed concrete uses low water/cement ratio so that desired strength and durability of concrete can be achieved.

XV. MIX PROPORTIONS OF CONCRETE

Mix proportion of concrete tells us the ratio of fine aggregates and coarse aggregates w.r.t. cement quantity. This can also be called as the aggregate cement ratio of concrete. The more cement is used, concrete becomes richer and aggregates will have proper lubrications for easy mobility or flow of aggregates. The low quantity of cement w.r.t. aggregates will make the less paste available for aggregates and mobility of aggregates is restrained.

XVI. SIZE OF AGGREGATES

Surface area of aggregates depends on the size of aggregates. For a unit volume of aggregates with large size, the surface area is less compared to same volume of aggregates with small sizes. When the surface area increases, the requirement of cement quantity also increase to cover up the entire surface of aggregates with paste. This will make more use of water to lubricate each aggregates. Hence, lower sizes of aggregates with same water content are less workable than the large size aggregates.

XVII. SHAPE OF AGGREGATES

The shape of aggregates affects the workability of concrete. It is easy to understand that rounded aggregates will be easy to mix than elongated, angular and flaky aggregates due to less frictional resistance. Other than that, the round aggregates also have less surface area compared to elongated or irregular shaped aggregates. This will make less requirement of water for same workability of concrete. This is why river sands are commonly preferred for concrete as they are rounded in shape.

XVIII. GRADING OF AGGREGATES

Grading of aggregates have the maximum effect on the workability of concrete. A well graded aggregates have all sizes in required percentages. This helps in reducing the voids in a given volume of aggregates. The less volume of voids makes the cement paste available for aggregate surfaces to provide better lubricating to the aggregates.

With less volume of voids, the aggregate particles slide past each other and less compacting effort is required for proper consolidation of aggregates. Thus low water cement ratio is sufficient for properly graded aggregates.

XIX. SURFACE TEXTURE OF AGGREGATES

Surface texture such as rough surface and smooth surface of aggregates affects the workability of concrete in the same way as the shape of aggregates. With rough texture of aggregates, the surface area is more than the aggregates of same volume with smooth texture. Thus concrete with smooth surfaces are more workable than with rough textured aggregates.

XX. USE OF ADMIXTURES IN CONCRETE

There are many types of admixtures used in concrete for enhancing its properties. There are some workability enhancer admixtures such as plasticizers and super plasticizers which increases the workability of concrete even with low water/cement ratio. They are also called as water reducing concrete admixtures. They reduce the quantity of water required for same value of slump.

Air entraining concrete admixtures are used in concrete to increase its workability. This admixture reduces the friction between aggregates by the use of small air bubbles which acts as the ball bearings between the aggregate particles.

XXI. USE OF SUPPLEMENTARY CEMENTITIOUS MATERIALS

Supplementary cementitious materials are those which are used with cement to modify the properties of fresh concrete. Fly ash, fibers, silica fume, slag cements are used as supplementary cementitious materials.

The use of fly ash in improves the workability of concrete by reducing the water content required for same degree of workability or slump value.

The use of steel or synthetic fibers in concrete reduces the workability of concrete as it makes the movement of aggregates harder by reducing the lubricating effect of cement paste.

The workability of concrete is reduced and increased based on the quantity of silica fume. The use of silica fume in concrete can improves workability when used at low replacement rates, but can reduce workability when added at higher replacement rates. Silica fume are used as pumping aid for concrete when used as 2 to 3% by mass of cement.

The use of slag cement also improves workability but its effect depends on the characteristics of the concrete mixture in which it is used.

XXII. CONCLUSION

With so many causes and types of cracks, it can be difficult to identify which cracks or defects indicate a more serious structural issue and which are simply architectural. Many cracks are caused by either overloading, corrosion, shrinkage, or poor workmanship. When looking at a specific cracking pattern or defect in concrete, sometimes the cause can be attributed to a specific reason. Other times the pattern may have multiple causes leading to its current state. In better understanding some of the causes of concrete cracks as well as different cracking pattern types, engineers, construction managers, and others may be able to avoid major structural catastrophes. If concrete is cracking when it should not be, it needs to be identified quickly and repaired before a structural failure.

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