International Journal of Current Advanced Research
ISSN: O: 2319-6475, ISSN: P: 2319-6505, Impact Factor: SJIF: 5.995
Available Online at www.journalijcar.org
Volume 6; Issue 8; August 2017; Page No. 5055-5057
DOI: http://dx.doi.org/10.24327/ijcar.2017.5057.0644

Research Article

DIAGNOSTIC APPROACH TO CONCRETE DURABILITY

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A R T I C L E I N F O

Article History:

Received 14th May, 2017
Received in revised form 11th June, 2017 Accepted 25th July, 2017
Published online 28th August, 2017

Key words:

Durability, Cracks, Porosity of Concrete, Deterioration, Carbonation, Sulphate Attack.

A B S T R A C T

Prior to undertake any repair or rehabilitation measure it is imperative to understand the process that leads to progressive deterioration of concrete and its causes. Appearing of cracks in concrete by itself is not the defect; indeed it is the manifestation of the defect. A keen understanding of crack mechanism and its contributors not only helps in arriving appropriate repair measure but also helps us to take precautionary measures during the mixing, placing and curing of concrete.

INTRODUCTION

A durable concrete retains its form, quality and serviceability during the course of its useful life span. Appearing of cracks, its promulgation and widening are mere symptoms prior to which concrete fails due to variety of reasons. Therefore repair measure must be initiated when concrete structure show cracks. During the course of investigation a deep sense of understanding on factors that hampers durability is much essential.

During its life period concrete definitely undergoes chemical and physical changes. In a durable concrete such changes take place at a rate so that there will not be harmful affects during the intended life of the structure.

It is interesting to know that concrete alone might be durable but with steel in Reinforced Cement Concrete (RCC), is not durable due to variety of reasons such as deviations during production, loading conditions in its service life and other attacks when exposed to environment.

As long as the capillary pores and micro-cracks are not interconnected the concrete remains water tight and thus durable.

Deterioration of Concrete

Concrete is subjected to deterioration at two distinct stages namely *Cracking Stage* and *Penetrability Stage*.

Cracking Stage

Due to the loading & weathering the voids and micro-cracks in the interfacial zone between the cement paste and coarse aggregate or reinforcing steel becomes inter-connected. When this network of inter-linked micro-cracks gets connected with any external or surface crack the pathways are created.

Penetrability Stage

Through the pathways made in the principal stage, the assaulting agents and dampness goes into the concrete, along these lines activating crumbling.

It can be very well comprehended that deterioration takes place due to simultaneous action of interconnected porosity and exposure to aggressive chemical in presence of water. In the absence of any of the three elements namely interconnected porosity, aggressive chemical and water the damage to RCC is rather highly likely.

Progression of Cracks

Low permeability of concrete is the major deciding factor for its durability. Prior to actual crack formation voids are developed in the concrete or in other wards concrete becomes permeable. Therefore making concrete impermeable to the possible extent is the major challenge.

Permeability (i.e. Interconnected Porosity) of concrete is a function of water-cement ratio, degree of hydration which intern depends on curing, air voids due to improper compaction, and micro-cracks due to loading and cyclic exposure to thermal changes. The table beneath demonstrates how different variables are identified with interconnected porosity with their affecting elements are appeared in Table 1.

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Table 1 Factors Influencing Inter-Connected Porosity

Factor	Influenced by
Capillary porosity	• High water-cement ratio • Inadequate curing
Air voids	• Improper compaction
Micro cracks	• Loading effects • Weathering • Initial care • After care • Secondary effects
Macro cracks	• Placement • Hardening process • Intrinsic chemical attack • Corrosion of reinforcement

Capillary Porosity

The volume of hydrated cement product is significantly higher than the volume of its constituents namely cement and water. Due to the process of hydration, increased volume of hydrated gel naturally fills part of capillary pore volume; thereby discontinuity in capillary pores is achieved. However decreasing in the hydration procedure won't give the full advantage from this phenomenon. Researchers have established that capillary porosity is less at lower water-cement ratios. Also at water-cement ratio of 0.4 the curing time required for capillary discontinuity is 3 days as against 1 year when water-cement ratio is more than 0.7are shown in Table 2.

Table 2 Curing Time Required for Different Water-Cement Ratios

Water-Cement Ratio by Mass	Curing Time Required for Capillary Discontinuity
0.40	3 days
0.45	7 days
0.50	14 days
0.60	6 months
0.70	1 year
more than 0.70	1 year

Air Voids

As a result of improper compaction, air voids in the form of discrete air bubbles does appear in concrete. Possible these voids get inter-connected by capillary pore system.

Micro Cracks

The potential reasons for micro cracks are *Cyclic Loading* and *Differential Thermal Exposure*. These when coupled with capillary porosity facilities ingress aggressive chemicals in RCC members.

Cyclic Loading

For the same intensity of loading beans subjected to cyclic loading shows deeper cracks when compared with beams subjected to static loads.

Differential Thermal Exposure

The structural members located on the exteriors are subjected to differential thermal loads, as result, tensile stresses in excess of tensile strength of concrete could develop across the cross section and result in formation of micro cracks. When this happens cyclically the cracks becomes deeper.

Macro Cracks

Despite of perfect design, quality ingredients and sound construction practices, there could be minimal cracks which are inevitable. Any crack width which facilitates the passage of aggressive chemicals is known as macro cracks.

Concrete Deterioration Due To Aggressive Chemicals

During the service period of an RCC structure, the deterioration is caused due to water tightness of cover concrete and percolation of aggressive chemicals through interconnected porosity, which attacks hydrated gel, aggregates and rebars.

Corrosion of Rebars

The products of cement hydration are highly alkaline in nature and thus p^H of hardened concrete ranges from 12.6 to 13.5. Therefore the steel in RCC is safeguarded by the passivating layer of concrete around. The two major causes that lead to the loss of latency of steel in concrete are:

1. Lessening of alkalinity of concrete surrounding the steel with p^H lower than 11 to 11.5.
2. Existence of chemicals which devastate the latency even while the alkalinity of surrounding concrete stay high.

The essentials for triggering corrosion of rebars in concrete are:

1. De-passivation of steel
2. Oxygen
3. Intermittent presence of water i.e. alternate wetting and drying

Carbonation

In areas where the concentration of carbon dioxide is high with a relative humidity of 50 % - 60 % associated with low cement content, high water cement ratio a reaction namely carbonation takes place due to which concrete alkalinity comes down and trigger corrosion of rebars. Penetration of carbon dioxide into concrete and subsequent chemical reaction the leads reduction of alkalinity of concrete is explained below:

$CO_2 + H_2O \rightarrow H_2CO_3$ (Carbonic acid)
$Ca(OH)_2 + H_2CO_3 \rightarrow CaCO_3 + 2H_2O$

Chlorides

Chlorides enter the concrete when it comes in contact with environment containing chlorides such as sea water or de-icing salts. Generally chloride intrusion starts the surface and creeps inwards. The process is time taking and essentially depends on:

1. The amount of chlorides that come contact with concrete
2. Permeability of concrete
3. Amount of moisture present

Chloride induced corrosion is very effective in the presence of moisture and associated with carbonation. Table.3 presents the tolerable crack width in reinforced concrete as suggested by ACI 224R-90.

Table 3 Tolerable Crack Width for Different Exposure Condition

Exposure Condition	Tolerable Crack Width (mm)
Dry air, protective membrane	0.41
Humidity, moist air, soil	0.30
De-icing chemicals	0.18
Seawater and seawater spray, wetting and drying	0.15
Water-remaining structures	0.10

Sulphate Attack

When water or soil having soluble sulphates such as sodium, calcium or magnesium sulphates comes in contact with concrete, they react with cement matrix and can form gypsum and ettringite. These compounds expand, pressurize and disrupt the paste. Due to this surface scaling and disintegration and finally mass deterioration takes place in the concrete.

Alkali Aggregate Reaction

Alkali aggregate reaction (AAR) may create expansion and severe cracking of concrete structures and concrete pavements. The actual mechanisms that cause alkali aggregate reaction are not fully understood. What is known about this type of reaction is that certain aggregates, such as reactive form of silica, react with potassium, sodium and calcium hydroxide from the cement and form a get around the reacting aggregates. When the gel round the aggregate is exposed to moisture, it expands, creating forces that cause tension cracks to form around the aggregate.

Other Factors Causing Deterioration

The other factors that can contribute to the deterioration of concrete are as follows:

- High water-cement ratio
- Inadequate curing
- Poorly graded aggregates
- Inadequate compaction
- Shuttering joints not slurry tight
- Cover thickness being lesser
- Wrong placement of reinforcement
- Wrong assessment of design loads
- Heating/ Cooling
- Wetting/ Drying
- Abrasion of surface

Summary

Concrete deterioration takes place at two stages namely Cracking Stage and Penetrability Stage. Capillary pores and air voids may interconnect due to various reasons and form the cracks. Under the favourable conditions such as moisture, reduction of concrete alkalinity due to carbonation chloride ion penetration may lead to corrosion of rebars in RCC. The factors that can hamper the durability of concrete may be at mixing & placing, curing or even at design stage as well.

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How to cite this article:

Chandrasekhar Reddy K (2017) 'Diagnostic Approach to Concrete Durability ', *International Journal of Current Advanced Research,* 06(08), pp. 5055-5057. DOI: http://dx.doi.org/10.24327/ijcar.2017.5057.0644

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