A Study on Long Term Reliability of Concrete Structures

Vikram[1], Dr. Awari Mahesh Babu[2]

[1]Research Scholar, OPJS University, Churu, Rajasthan
[2]Professor, OPJS University, Churu, Rajasthan

Abstract

Because of its low cost, flexibility, and adaptability, concrete is the most popular and commonly utilized construction material. Since reinforced concrete structures have failed to satisfy the design service life requirement, the inclusion of durability and service life prediction has grown greater relevance in recent years. The corrosion of the reinforcing bar when exposed to a hostile environment caused most of the concrete constructions to deteriorate prematurely. Traditional prescriptive specifications are unsuccessful in predicting service life since they are based on restricted values of mix design parameters. Performance specification, on the other hand, entails the measurement of relevant durability that can be utilized as input parameters in a service life model to estimate the structure's durability.

Keywords: Durability; Quality assurance; chloride; service life.

I. INTRODUCTION

Concrete's endurance is affected by a variety of issues, including degradation due to external chemical assault and corrosion of the reinforcing bar in the presence of chloride ions. Chloride-induced corrosion of reinforcing bars is a key hazard in the maritime environment. The rate of chloride-induced corrosion is mostly determined by the concrete's permeation and diffusion characteristics. Another key concern affecting the durability of reinforced concrete structures is concrete carbonation in industrial regions, which is influenced by the permeation characteristics of concrete.

The current approach in the concrete industry for durability design is based on the limiting values of selected mix design specifications, with the premise that if the strength standards are met, the concrete will be adequately durable in any demanding environment. Nonetheless, studies have demonstrated that compressive strength and durability metrics do not have a unique connection. Chemical and mineral admixtures, concrete binder type, and building processes all affect durability. The prescriptive method fails to include these aspects.

The attributes that can be connected to the durability issue of reinforced concrete buildings under the prevalent exposure situation are used to develop performance criteria. It may be used to provide a rational foundation for predicting durability and designing service life. The performance-based specification technique may be used at several phases of the structure's development, including design, prequalification, and confirmatory evaluation.

II. CONCRETE STRUCTURES

High performance concrete was developed as a result of the early degeneration of concrete structures in aggressive environments, such as airport runways, railway sleepers and nuclear reactors. Other applications include prestressed concrete bridges, skyscrapers, offshore platforms, chimneys and silos. It is thus thought of as durable concrete when it has an impermeable porosity or a low porosity. By doing so, concrete becomes more resistant to the entry of potentially dangerous compounds such as chloride and sulfate ions, carbon dioxide, water and oxygen, as well as other gasses.

1. Micro Structure Of HPC

Porosity refers to the range of pore size and connectivity in concrete, which makes it a porous material. In order to prevent corrosion, expansion, and cracking in the concrete, this porosity limits the permeability of concrete. Filling the gap between the cement particles and the aggregate with mineral additives (or finer pozzolan) creates dense packing in concrete. As a result of this, concrete will be more resistant to a hostile environment.

2. High Performance Concrete

As a result of the increased properties of HPC concrete (higher elastic modulus concrete), which was discovered to have a low water/cement or water/binder ratio, the term "HPC concrete" was coined. Concrete with a low water/binder ratio is referred to as high performance concrete. High-performance concretes are defined as having a coefficient of approximately 0.40. Hence, the water/binder ratio determines whether or not concrete is considered excellent performance.

Using conventional components and standard mixing, pouring, and curing techniques, the American Concrete Institute (ACI) defines high performance concrete as concrete that meets a unique set of performance and uniformity standards that cannot be frequently accomplished. Commentary to the definition specifies that a high-performance concrete is one that has been produced for a specific use or environment. It is impossible to use the same concrete for diverse purposes.

As a result, the particular definition of HPC requirements for each industrial application is likely to differ. Concrete with the best durability for a particular strength class is referred to as high performance. It's not fair to make comparisons between concretes with varying strengths. A better (longer-lasting) concrete is possible, as long as one has access to the information necessary to do it. High paste volume in an HPC with just cement as a binder results in severe shrinkage and a considerable development of hydration heat, as well as an increased cost.

Concrete's durability might be improved by using mineral additives such as fly ash, silica fume, and finely ground blast furnace slag to replace some of the cement in the mix. Additional advantages include cost savings, energy savings, fostering ecological balance, and protection of natural resources, as a result of this change in policy.

- **Role of aggregates in HPC**

Concrete's dimensional stability and wear resistance may be attributed to the use of aggregates. Concrete's mechanical and physical qualities are influenced by these additives, as well as strength and durability. There should be no unwanted contaminants or chemical instability in aggregates. Neither the cement nor any of the other components in concrete should be harmed by these additives. They should be devoid of organic materials and contaminants that might interfere with the cement's hydration process. Aggregate properties have a significant impact on the workability, strength, durability, and moisture susceptibility of concrete.

The workability of fresh concrete and its hardened strength are both influenced by the size and grade of the particles used in the mix design. The majority of the aggregates used in concrete are made from naturally occurring materials, although some concrete may also include synthetic aggregates. To increase the mechanical qualities of concrete, these artificial and treated particles react chemically with the cement paste. Slag aggregates are flat or long-shaped particles of steel that are about cubical in form and have an angular shape.

With more non-interconnected cells, they have a higher surface area than smoother aggregates of equivalent volume; this property aids in cement paste adhesion, making them ideal for use in construction. For this reason, the steel slag has very high shear strength as well as a high degree of internal friction. Steel slag aggregates outperform hard conventional rock aggregates in the vast majority of physical qualities. Steel slag has a number of advantages, some of which are outlined here.

1. They're very sturdy and long-lasting.

2. Interlocking characteristics are enhanced by their outstanding angular form.

3. High abrasion and impact resistance is one of its many strengths.

- **Role of mineral admixtures in HPC**

The silica in mineral admixtures reacts with the calcium hydroxide (CH) generated during cement hydration when added to concrete. In addition, it produces more calcium silicate hydrate (C-S-H), enhancing the concrete's toughness and mechanical qualities. Calcium hydroxide, formed during the hydration of cement in concrete, may be counteracted by adding mineral admixtures such as fly ash, silica fume, and metakaolin. Compared to standard portland cement, these mineral admixtures create a lower amount of CH. These mineral admixtures only consume CH during the pozzolanic process, not produce it. Cement paste is made more durable by consuming CH, which makes the paste more thick and impermeable.

- **Role of fly ash in HPC**

Coal-fired power stations' fly ash is widely regarded as a pozzolanic substance that may be used as a mineral additive in concrete or as a component of blended portland cement. Fly ash dose in commercial usage is restricted to 15% to 30% of the total cementitious material mass. Concrete's workability and economics benefit greatly from this quantity. Fresh concrete's characteristics might be affected by the quality and source of fly ash. Cohesiveness and decreased bleeding capacity are two advantages of using fly ash in concrete mix. Fly ash has a comparable effect on water demand as a superplasticizer.

Using fly ash, the portland cement particles are dispersed and absorbed by the material. The release of sulphur trioxide ions from the surface of fly ash particles slows the reaction time by around an hour. Consequently, the initial setting is pushed back. The period between the first and final settings, on the other hand, is not altered. Adding fly ash to portland cement increases the dispersion of the particles, increasing their reactivity, according to research. Concrete and fly ash particles are both involved in the chemical process. The setting time of fly ash-based concrete is longer than that of conventional concrete.

- **Role of silica fume in HPC**

To increase the workability of concrete, silica fume may be added to a concrete mix. The improved dispersion of the cementitious particles is to blame for this. Since silica fume particles are smooth and absorb very little water during the mixing process, they have a low water absorption rate. This means that fluctuations in water content may have a greater impact on the workability of silica-fume-based cement because of the fineness of the silica fume particles. Reduces the freezing and thawing impact thanks to its limited penetrability and resistance to chloride ion penetration.

- **Role of chemical admixtures in HPC**

It is necessary to add chemical admixtures or superplasticizers when using mineral admixtures in concrete. Chemical admixtures, also known as superplasticizers, have the primary function of increasing the workability of concrete by fluidizing the mixture. Repulsion induces deflocculation and an increase in the fluidity of the mix when a superplasticizer is added to a concrete mix.

3. Water / Cement, Water / Cementitious Materials or Water / Binder Ratio

Insofar as Portland cement is the only cementitious ingredient present in concrete, the water-to-cement ratio is straightforward and easy to understand. The use of so-called "supplementary cementitious materials" or "fillers," such as fly ash, slag, natural pozzolan, silica fume, limestone filler, silica filler, or rice husk ash, has become increasingly standard practice in contemporary concrete. Binders are a term for these finely developed materials. Water/binder ratio (w/b) is used instead of the more cumbersome 'water/cementitious materials ratio' since it is easier to remember.

4. Supplementary Cementitious Materials

Portland cement may be used as a cementitious ingredient to produce high-performance concrete. A partial replacement of Portland cement by one or more extra cementitious materials may be beneficial, not only from a financial standpoint but also from a rheological and, in certain cases, strength perspective. At room temperature, reactive silica included in most additional cementitious materials may interact with lime to generate calcium silicate hydrates of the same sort as those formed during the hydration process for Portland cement. For the most part, the pozzolanic reaction may be expressed as follows.

At room temperature, this reaction is typically sluggish and might take many months to reach its final state.. However, the reaction of finer pozzolan with lime was more rapid.

5. Chemical Admixtures

Polycondensate of naphthalene and formaldehyde sulfonated salts, often known as polynaphthalene sulfonate or simply naphthalene superplasticizers, are commonly used in plastics manufacturing. Cement and superplasticizer compatibility is best assessed by examining the flow properties of a certain grout, mortar, or concrete in relation to the cement and superplasticizer.

6. Structural use of HPC

Increasing the use of high-performance concrete in high-rise construction is the best way to decrease creep and shrinkage. As a consequence, concrete members' deflections are minimized. The lateral stiffness of a high rise structure is improved when high performance concrete is utilized for the columns, thereby minimizing the lateral sway produced by wind loads. Using high performance concrete in high rise construction not only results in more slender buildings, but it also reduces the need for steel, lowering the dead load.

7. Porosity

When making hydrated cement paste, the ratio of water to silicate paste, as well as the quantity of air trapped during mixing, are the most important considerations. Feret, who coined the famous term in 1892, was the first to notice this:

For the hydrated cement paste, f'c is the compressive strength of the hydrated cement paste, 'Cv' is the volume of cement, 'Wv' is the volume of water and 'av is the volume of air'

- When the numerator and denominator are divided by 'Cv', Feret's formula may be rewritten:
- Entrapped air volume in hydrated cement paste or concrete is normally below 1 to 2 percent of the overall volume, therefore it may be ignored. As a result, Feret's statement may be written as
- It is evident that a decrease in the water/cement ratio is required to improve compressive strength.

III. CONCRETE DURABILITY

A concrete structure is said to be durable if it can withstand weathering, chemical assault, aberration, or any other kind of degradation under a particular exposure situation without requiring extensive maintenance and repair. As a result, it is critical to evaluate the possibility of a concrete structure's endurance in a certain environment over its service life while preparing specifications. The durability of reinforced concrete structures involves a wide variety of issues that will impact the structure's serviceability. Corrosion of the reinforcing bars and concrete degradation due to external chemical assault are the two key difficulties that account for the majority of the repair and rehabilitation costs.

Concrete's durability refers to its capacity to endure environmental degradation. It refers to a material's or structure's capacity to sustain its design service life without substantial degradation. The American Concrete Institute defines concrete durability as resistance to weathering, chemical attack, and other degradation processes, whereas the British Standard defines a durable concrete as one that is designed and constructed to protect embedded reinforcement from corrosion and should perform satisfactorily in the working environment for the structure's lifetime. The requirements relating to durability, which are in accordance with other international standards, have been tightened to give more attention to durability concerns.

Traditional Prescriptive Approach for Concrete Durability

The prescriptive approach contains specifications for raw material qualities and building methods. Concrete strength, as well as the water-cement ratio, are used to assess the quality and longevity of the material. Due to the exposure circumstances, these values are restricted. The theory is most likely based on the direct link between the water-cement ratio and concrete quality. For the same exposure scenario, the limiting values of water-cement ratio and minimum cement content vary by country.

Because concrete was created without significant chemical or mineral admixture in previous decades, its longevity could be linked to its strength and microstructure, and hence to the binder concentration. However, admixtures are in considerable demand these days, and they appear to have an impact on concrete durability. The minimal cement content can be used to limit permeation, diffusion, and absorption qualities. The lower water-to-cement ratio results in better strength and durability. However, there was no link between durability and a lower water-cement ratio. The prescriptive specification fails to provide specifications based on concrete performance under certain exposure conditions.

The quality and depth of the cover concrete is a key factor in the concrete's longevity under a particular exposure environment. The quality of cover concrete is determined by the mixing, putting, compacting, and curing procedures, as well as the proportioning of the mix. The strength test of the specimen created on site is determined to be more realistic than the quality measurement of cover concrete.

Performance-Based Specification for Durability

The performance of a constructed structure is measured with appropriate durability criteria depending on the application and exposure situation in a performance-based standard. The performance-based durability design takes into account the material's strength, durability criteria, and exposure conditions. The durability indicator values of actual concrete for a given climate can be used to estimate a concrete structure's resistance to degradation. In the event of reinforcement corrosion, evaluating the cover concrete for appropriate durability parameters aids in predicting the infiltration of dangerous substances from outside the concrete. The test methodologies and acceptance criteria should be explicitly established in the performance-based approach, which may be done during the pre-qualification or build structure quality acceptance stages of construction.

The water-cement ratio affects the concrete's strength and microstructure. The overall pore volume is directly proportional to the strength. However, the size, kind, and continuity of the pores in the concrete are crucial in terms of durability. Because it is dependent on the building process and curing efficacy, the quality of cover concrete is becoming increasingly important. Thus, the quality of the structure's cover concrete is determined by evaluating the durability characteristics of actual concrete on the field. The fundamental premise of performance-based specification is this. The needed level of concrete quality is supplied in terms of long-term durability by ensuring the limiting values of concrete durability indicators at a specific age. Based on the durability index values of laboratory manufactured specimens, performance-based durability indicator values can be determined for a specific mix. Testing if the site concrete has met the intended specification value aids in ensuring the completed product's quality.

IV. DURABILITY PROBLEMS

The following are the durability issues that arise in arranged force the concrete structure:

Sulphate attack

When sulphate ions penetrate into concrete, they react with the hydration products already there, primarily calcium hydroxide, to produce more ettringite and gypsum. The production of delayed ettringite and gypsum induces expansion, which leads to fracture formation. The ambient temperature, amount of mineral additives, water cement ratio, diffusivity, permeability qualities of concrete, and sulphate ion concentration are the primary factors that impact sulphate attack. Variations in length, mass, surface hardness, strength, and elastic modulus are commonly used to assess the impact of sulphate assault.

Corrosion due to chloride ingress

There are two types of chlorine that seep into concrete: bound chloride and free chloride. The bound chloride is the chloride that is either adsorbed in the pore or chemically attached to the hydration product. The rate of additional chloride intrusion is influenced by the bound chloride. The corrosion of the reinforcing bar is caused by free chlorine. The chloride ions have the ability to counteract the alkaline cement paste's corrosion-preventative capabilities. Despite the fact that the role of chloride ions in corrosion is complicated, the most widely accepted idea is that it aids in the breaking of the passive layer of iron oxide that forms around the reinforcement. The concentration of free chloride must surpass the chloride threshold value before corrosion can begin, which is normally determined by the concrete composition and environmental factors.

The activity of the chloride in the concrete is a complicated process. Calcium aluminoferrite and chloro ferrite hydrate are formed when the C3A and C4AF react with chloride ions. The corrosion process is not affected by this fixed chloride. The closeness of saltwater, sharing technique, water-cement ratio, binder type, and air void content all impact the rate of chloride penetration.

Carbonation

Calcium carbonate is formed when carbon dioxide diffuses into the concrete and interacts with calcium hydroxide. Concrete is a strongly alkaline medium that prevents corrosion of the reinforcing bar. Calcium carbonate production lowers the pH of concrete to below 10. If carbonation gets close to the reinforcing bar, it can erode the passive layer around it, causing corrosion in the presence of water. When the pH of the environment falls below 11, the passive layer around reinforcement is easily damaged. The carbon dioxide will also react with the CSH gel, which will disintegrate into calcium carbonate and a porous amorphous Silica Gel. By modifying the porosity structure of concrete, carbonation products will improve permeability. Carbonation can also impact chloride ion binding capability, resulting in an increase in free chloride ion concentration in concrete. In practice, the combination of carbonation and chloride ingress is likely to generate more serious corrosion issues. Concrete's gas permeability and water absorption qualities are linked to carbonation.

Freeze and thaw action

The freeze-thaw cyclic effect occurs when a concrete specimen is saturated with water and the temperature drops below freezing. The water freezes and produces up to a 9 percent expansion from the original volume. The damage to concrete caused by small fractures that get larger over time. Freeze-thaw eventually resulted in concrete surface spalling or scaling.

V. IMPLEMENTATION OF PERFORMANCE – BASED SPECIFICATION

Performance requirements are designed to identify and assure the necessary degree of concrete quality in relation to long-term durability in the structure's service environment. The owner and designer bear primary risk in a prescriptive specification; performance specifications separate and assign risk and responsibilities more explicitly. The risk and liability associated with the concrete as provided and the concrete as placed in the structure are separated by defining and measuring the concrete as supplied and the concrete as placed in the structure separately. Furthermore, prescriptive specifications are concerned with providing comprehensive information of inputs (i.e., materials) and processes in order to assure proper quality and create appropriate monitoring and inspection levels. Waiting until the allocated period in a performance specification has passed before testing the durability (or other performance) metrics and making payment for construction would be reasonable. It was suggested that the two techniques are inefficient in their purest versions, and that to implement hybrid needs, an intermediate methodology should be utilised (with greater focus on performance criteria). In this process, the owner and designer decide on the desired output standard and offer relevant 'index' or indicator tests that are used to produce specifications in the specific service context. The supplier and contractor now have a concrete system that fulfils the owner/index designer's requirements (or restrictions) (which is prequalified using tests performed before actual construction). The "concrete system" comprises not only the quantities of the mixture, but also the specifics of the concreting processes used.

"A collection of unambiguous, quantifiable, and enforceable instructions that specify the application-specific functional requirements for hardened concrete," according to performance criteria.

"Performance-based standards" are reported to address mechanical and functional criteria for concrete. "Performance-based specifications" are known to be free of process constraints such as mixture proportions and building methods. Greater competence in mixture proportioning, improved material selection, and lower unpredictability can all lead to higher-quality concrete.

Prescriptive requirements are seen to be of limited use to concrete producers since they limit the scope of application of new technologies to mixture proportioning procedures. Prescriptive criteria in the production and usage of concrete, according to some, limit creativity. It also said that prescriptive specifications have a place when a project provides previously unimagined obstacles or possibilities, and a highly talented and experienced technologist has been hired to agree on a solution with the finest producer available. In all other circumstances, regardless of national rules or local industry standards, it will be prudent for the agencies of any significant project to agree on a performance basis with a chosen supplier. An acceptable specification must meet two different requirements: (a) give an accurate assessment of concrete quality, and (b) take quick action in the case of a quality decline.

V. CONCLUSION

A specification is a precise explanation of the owner's expectations for a finished project from the contractor. The two sorts of specifications are prescriptive and performance. The prescriptive standards address material quality, amounts, mixing and transportation processes, as well as a variety of activities including placement and curing. The key to increasing reinforced concrete longevity is ensuring that as-built buildings fulfil crucial performance requirements for degradation mechanisms.

The aggressiveness of the environment, the materials used in construction, quality control during concrete placement, and the quality of the cover concrete are the key variables determining the degradation of RC structures. Depending on the exact durability requirements, RCPT, RCMT, sorptivity, water permeability, concrete resistivity, OPI, and other regularly used test techniques can be employed separately or in combination.

REFERENCES: -

1. Bhaskar Sangoju, Ramesh Gopal, Bharatkumar Bhajantri H. “A review on performance-based specifications toward concrete durability”. Structural Concrete. 2020;1–13, 2020
2. H. Beushausen, R. Torrent, and M. G. Alexander, “Performance-based approaches for concrete durability: State of the art and future research needs,” Cem. Concr. Res., vol. 119, no. January, pp. 11– 20, 2019, doi: 10.1016/j.cemconres.2019.01.003.
3. Bhattacharjee, Bishwajit. (2012). Some issues related to service life of concrete structures. Indian Concrete Journal. 86.
4. Rumšys, Deividas & Spudulis, Edmundas & Bacinskas, Darius & Kaklauskas, Gintaris. (2018). Compressive Strength and Durability Properties of Structural Lightweight Concrete with Fine Expanded Glass and/or Clay Aggregates. Materials. 11. 10.3390/ma11122434.
   Folic, Radomir. (2015). SOME ASPECTS OF DESIGNING CONCRETE STRUCTURES BASED ON DURABILITY S. Grković1, R. Folić.
5. Qureshi, Tanvir. (2011). Reinforced concrete structure design based on concrete mix characteristic length. 10.13140/RG.2.1.2453.1444.
6. ACI 201.2R. “Guide to durable concrete”. USA: ACI (American concrete institute) Publication, 2017
7. Santhanam M. (2013). “Durability and performance specifications”, The Master Builder, March, 100–114
8. Nganga G, Alexander MG, Beushausen H. “Performance-based durability design for RC structures”. Int J 3R's. 2011;2(3): 281–290
9. Otieno M, Beushausen H, Alexander M. “Prediction of corrosion rate in reinforced concrete structures—A critical review and preliminary results”. Mater Corros. 2011;62:1–14
10. M. G. Alexander, M. Santhanam, and Y. Ballim, “Durability design and specification for concrete structures—the way forward,” Int. J. Adv. Eng. Sci. Appl. Math., vol. 2, no. 3, pp. 95–105, 2010, doi: 10.1007/s12572-011-0027-x.
11. Alexander MG, Santhanam M, Ballim Y. “Durability design and specification for concrete structures—the way forward”. Int J Adv Eng Sci Appl Math. 2010;2(3):95–105
12. Gjørv OE (2009) Durability design of concrete structures in severe environments. Taylor & Francis, London, 232 pp. ISBN:978-0-415-41408-1