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A REVIEW ON CONCRETE DURABILITY AND PERFORMANCE–BASED SPECIFICATION

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Abstract - *In recent years the incorporation of durability and service life prediction has gained more importance since the reinforced concrete structures were failed to meet the design service life requirement. The premature deterioration of most of the concrete structures resulted from the corrosion of the reinforcement bar when exposed to an aggressive environment. The traditional prescriptive specification is based on the limited values of mix design parameters and is found to be ineffective in service life prediction. In contrast, performance specification involves the measurement of relevant durability that can be used as input parameters in the service life model to predict the durability of the structure. This paper presents a review of durability issues of the reinforced concrete structure and the concept of performance specification based on the South African approach.*

Key Words: Durability, Performance-based specification, Prescriptive specification, Durability index, Carbonation, chloride ingress

1. INTRODUCTION

The durability of concrete involves various problems such as deterioration of concrete due to the external chemical attack and the corrosion in the reinforcement bar in the presence of chloride ion. In the marine area, chloride-induced corrosion of reinforcement bar is the major concern. The chloride-induced corrosion rate is dependent mainly on the permeation and diffusion properties of concrete. Another major durability issue of reinforced concrete structures is the carbonation of concrete in the industrial areas, which is also governed by the permeation properties of concrete.

Current practice for durability design in the concrete industry is based on the limiting values of selected mix design specification with the assumption that if the strength criteria is satisfactory then the concrete is sufficiently durable in any aggressive environment. Nevertheless, researches have shown that there is no such unique relationship between compressive strength and durability parameters. Durability parameters depend on the chemical and mineral admixture, Binder type of concrete, and construction methods. These factors are failed to incorporate into the prescriptive approach.

Performance specifications are based on the properties that can be linked to the durability issue of reinforced concrete structures under the prevalent exposure condition. It can be used to form a logical basis for durability prediction and service life design. Performance-based specification approach can be involved in different stages of the construction of structure like design, prequalification and confirmatory evaluation of the built structure. In the South African performance-based approach the durability assessment is done with the help of durability index values[1].

2. CONCRETE DURABILITY

A concrete structure is said to be durable if it can resist weathering action, chemical attack, aberration, or any form of deterioration without excessive maintenance and repair cost in a given exposure condition. Thus it is important to take into consideration the possible durability issue on a concrete structure in a specific environment in its service life during the preparation of specification. The durability of reinforced concrete structure includes a wide range of problems which will affect the serviceability of the structure. Among them, corrosion of the reinforcement bar and the deterioration of the concrete due to the external chemical attack are the major issues which account the largest portion of repair and rehabilitation cost.

The permeation of liquid, gas, or ions into the concrete core and its interaction with the pore water and constituent of concrete plays an important role in the durability of reinforced concrete structures. Permeation properties of concrete influenced by the size, shape, type, and distribution of pores in the cement paste and aggregate. The total volume of pores is a concerning factor in the case of strength and elasticity[2]. However, in the case of permeability properties the size of the pores and their interconnectivity plays a vital role. The pore size greater than 50 mm is responsible for the permeability of concrete and the free water existing on these pores is responsible for the permeation of external receive agents into the concrete[3].

Depending on the nature of transport matter and navigation force the transport process in the concrete can be classified as absorption, adsorption, sorption, permeability, migration, convection, and diffusion. The transport of external matters into the concrete core occurs only when the concrete is in a unsaturated or partially saturated state with their relative humidity greater than 40 percent. The very high or low relative humidity is unfavorable for the permeation of external matters into the concrete and unless an external navigating force is existing.

Durability problems existing in arranged force the concrete structure are as follows,

1. Sulphate attack

When the sulphate ions diffuse into the concrete, it react with the hydration products existing on the concrete mainly calcium hydroxide, and forms additional ettringite and gypsum. The formation of delayed ettringite and gypsum causes the expansion and thereby formation of cracks. The major factor which influences the sulphate attack is the ambient temperature, amount of mineral additives, water-cement ratio, diffusivity, permeability properties of concrete, and the concentration of sulfate ions[4]. The effect of sulphate attack is usually measured with the variation of length, mass, surface hardness, strength, and elastic modulus.

2. Corrosion due to chloride ingress

The chloride which diffused into the concrete can be divided into two, bound Chloride and free chloride. The chloride which is either adsorbed in the pore or chemically bonded to the hydration product is known as the bound chloride. The bound chloride influences the further chloride ingress rate. The free chlorine is responsible for the corrosion of the reinforcement bar. The chloride ions have the property to negate the corrosion inhibiting properties of the alkaline cement paste. Even though the role of chloride ions in corrosion is complex, the most accepted theory is that it helps to break the Passive layer of iron oxide formed around the reinforcement. Before starting the corrosion the concentration of free chloride must exceed the chloride threshold value, which is usually influenced by the concrete composition and environmental parameters[5].

The action of chloride present in the concrete is a very complex process. The C3A and C4AF combine with chloride ions and form calcium aluminoferrite and chloro ferrite hydrate[6]. This fixed chloride does not participate in the corrosion process. The chloride ingress rate is influenced by the proximity of seawater, sharing method, water-cement ratio, binder type, air void content.

3. Carbonation

When carbon dioxide diffuses into the concrete it reacts with calcium hydroxide forms calcium carbonate. Concrete is a highly alkaline medium, which protects the reinforcement bar from corrosion. The formation of calcium carbonate will decrease the pH of concrete below 10. If the carbonation reaches near the reinforcement bar it can destroy the passive layer around the reinforcement bar and starts corrosion in the presence of water[7]. The passive layer around reinforcement can be easily destroyed when the pH of the surrounding is below 11. The carbon dioxide will also react with CSH gel, which will decompose into calcium carbonate and an amorphous Silica Gel with a porous structure. The carbonation products will increase the permeability of concrete by altering the porous structure. The carbonation can also affect the binding capacity of chloride ions and resulted in the increase of free chloride ions concentration in the concrete. The combination of carbonation and chloride Ingress is likely to cause more severe corrosion problems in practice. The carbonation is correlated with the gas permeability and water absorption properties of concrete[8].

4. Freeze and thaw action

When the concrete specimen is saturated with water and the temperature falls below the freezing value, the water gets frozen and causes up to 9% expansion from the original volume is termed as the freeze-thaw cyclic effect. The distress caused in the concrete from tiny cracks, which become large over time. Eventually, freeze-thaw ended up in spalling or scaling of concrete surface[2].

3. TRADITIONAL PRESCRIPTIVE APPROACH FOR CONCRETE DURABILITY

The prescriptive approach includes the specification for properties of raw materials and construction procedures. The strength of concrete is used as a parameter for measuring the quality and durability of concrete along with the water-cement ratio. These values are limited based on the exposure condition. The principle is probably based on the direct relationship between the water-cement ratio and the quality of concrete. The limiting values of water-cement ratio and minimum cement content change for the different countries for the same exposure condition.

In the past decades, the concrete was made without much chemical or mineral admixture, thus the durability of concrete was able to relate to the strength and microstructure and thereby a relation with the binder content. However, nowadays admixtures are using in high demand and it turns out to be influencing concrete durability. The permeation, diffusion, and absorption properties can be limited by using minimum cement content. The reduced water-cement ratio gives increased strength and improved durability properties. However, the durability and reduced water-cement ratio didn't show any valid relationship. The prescriptive specification is failed to incorporate specification based on the performance of concrete in a given exposure condition[1].

The cover concrete quality and depth is an important parameter in the concrete durability in a given exposure condition. The quality of cover concrete depends on the quality of construction including the mixing, placing, compacting, and curing methods along with the mix proportioning. The quality measurement of cover concrete is found to be more realistic than the strength test of the specimen prepared on the site.

4. PERFORMANCE-BASED SPECIFICATION FOR DURABILITY

In the performance-based specification, the performance of a built structure is measured with suitable durability parameters depending on the application and exposure condition. The strength, durability parameters of the material, and exposure condition are used in the performance-based durability design. The durability indicator values of the actual concrete for a particular environment will help to predict the resistance of a concrete structure against deterioration. In the case of reinforcement corrosion the testing of cover concrete for suitable durability parameter help in estimating the ingress of external harmful substance in the concrete. In the performance-based approach, the test methods and acceptance criteria should be clearly specified, it can be done in either pre-qualification or build structure quality acceptance stage of construction[9].

The strength and microstructure of the concrete are depended on the water-cement ratio. The strength is directly dependent on the total pore volume. However, in the case of durability, the size, type, and continuity of the pores in the concrete is important. The quality of cover concrete is having more importance since it depends on the construction process and the effectiveness of curing. Thus by measuring the durability parameters of actual concrete on the field give the quality of cover concrete of the structure. This is the basic principle of performance-based specification.

In terms of long-time durability, the required level of concrete quality is issued by ensuring the limiting values of durability indicators of concrete at a particular age. The performance-based durability indicator values can be set for a particular mix based on the durability index values of the laboratory prepared specimens. By testing whether the site concrete has achieved the desired specification value helps to ensure the quality of the finished product[1].

Some of the national standards already include the performance-based approach along with the prescriptive approach. In many countries, even though the durability design is still based on the prescriptive specification the quality of site concrete is assured with the performance-based specification. In India, some of the major construction projects like Metro and Kudankulam power plant include that durability-based specification which is needed to be fulfilled by the actual concrete were included in the clauses[10].

4.1. Durability Index Tests

In the South African performance-based approach three durability index tests are proposed in addition to the compressive strength. The three durability index tests are oxygen permeability index water sorptivity and Rapid chloride permeability. This durability index value is an idea about the transport mechanism by reflecting the pore structure distribution and its interconnectivity. The test specimens are 70±2 mm diameter and 30±2 mm thick disease condition at 50°C for seven days[1].

1. Oxygen permeability index

The oxygen permeability value is defined as a negative log of the D'Arcy coefficient of permeability k (m/s) obtained from the falling head permeability gas test. The value is influenced by the amount and interconnectivity of pores which is resulted from poor compaction and bleeding. The values usually range from 8 -11. The higher value indicates a lower permeability[11].

2. Water sorptivity

The water sorptivity test measures the uptake of water by capillary suction in concrete. What sorptivity gives the measure of effectiveness and nature of curing, since it is sensitive to the near-surface properties of the concrete. The sorptivity value ranges from 5 mm/h for the well-cured specimen of M30 - M50 grade to 15 - 20 mm/h for poorly cured M20 grade concrete[11].

3. Rapid Chloride conductivity

The test measures the conductivity of the specimen when highly saturated with chloride solution. The test is sensitive to the binder type and additives present in the concrete[12]. The Rapid chloride conductivity is related to the chloride diffusion properties of the concrete. The value ranges from 2.5 mS/cm for OPC to. 5 mS/cm for blended cement[11].

5. CONCLUSIONS

A specification is a detailed description that establishes the owner's expectations of the contractor for a completed project. Prescriptive and Performance are the two types of specifications. Materials qualities, quantities, mixing and transporting techniques, and a range of operations, such as placing and curing, are all covered by the prescriptive specifications. The key to improving reinforced concrete durability is that as-built structures meet critical performance criteria in respect of probable modes of deterioration.

The main factors influencing the deterioration of RC structures are the aggressiveness of the environment, the materials used in construction, quality control during concrete placement, and the quality of the cover concrete. RCPT, RCMT, sorptivity, water permeability, concrete resistivity, OPI, and other commonly used test methods can be used independently or in combination, depending on the specific durability requirements.

REFERENCES

[1] 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.

[2] S. V. Nanukuttan *et al.*, "The performance of concrete exposed to marine environments: Predictive modelling and use of laboratory/on site test methods," *Constr. Build. Mater.*, vol. 93, pp. 831–840, 2015, doi: 10.1016/j.conbuildmat.2015.05.083.

[3] P. K. Mehta and P. J. M. Monteiro, "Microstructure , Properties and Materials," 2001.

[4] S. W. Tang, Y. Yao, C. Andrade, and Z. J. Li, "Recent durability studies on concrete structure," *Cem. Concr. Res.*, vol. 78, pp. 143–154, 2015, doi: 10.1016/j.cemconres.2015.05.021.

[5] G. R. Meira, C. Andrade, E. O. Vilar, and K. D. Nery, "Analysis of chloride threshold from laboratory and field experiments in marine atmosphere zone," *Constr. Build. Mater.*, vol. 55, pp. 289–298, 2014, doi: 10.1016/j.conbuildmat.2014.01.052.

[6] L. Chernin, "Effect of corrosion on the concrete-reinforcement interaction in reinforced concrete beams," no. September 2008, 2015.

[7] E. Rozière, A. Loukili, and F. Cussigh, "A performance based approach for durability of concrete exposed to carbonation," *Constr. Build. Mater.*, vol. 23, no. 1, pp. 190–199, 2009, doi: 10.1016/j.conbuildmat.2008.01.006.

[8] I. S. Yoon, "Deterioration of Concrete Due to Combined Reaction of Carbonation and Chloride Penetration: Experimental Study," *Key Eng. Mater.*, vol. 348–349, pp. 729–732, 2007, doi: 10.4028/www.scientific.net/kem.348-349.729.

[9] C. Lobo, L. Lemay, and K. Obla, "Performance-based specifications for concrete," *AEI 2006 Build. Integr. Solut. - Proc. 2006 Archit. Eng. Natl. Conf.*, vol. 2006, no. March, p. 45, 2006, doi: 10.1061/40798(190)45.

[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] M. G. Alexander, Y. Ballim, and K. Stanish, "A framework for use of durability indexes in performance-based design and specifications for reinforced concrete structures," *Mater. Struct. Constr.*, vol. 41, no. 5, pp. 921–936, 2008, doi: 10.1617/s11527-007-9295-0.

[12] A. A. Du Preez and M. G. Alexander, "A site study of durability indexes for concrete in marine conditions," *Mater. Struct. Constr.*, vol. 37, no. 267, pp. 146–154, 2004, doi: 10.1617/13998.