Performance specifications for concrete construction in India: Are we ready?

B.S. Dhanya and Manu Santhanam

This paper addresses the shift towards performance based specifications in the worldwide concrete construction industry, and takes stock of the prevailing situation in India. Examples from live construction projects in India, where durability has been specified, are presented and analysed. The paper also provides a discussion on the way forward towards successful implementation of durability specifications in concrete construction projects.

Introduction

Durability of hydraulic-cement concrete is defined as its ability to resist weathering action, chemical attack, abrasion, or any other process of deterioration (ACI). Durable concrete will retain its original form when exposed to its service environment.

Concrete durability problems may arise from the concrete system or due to the aggressiveness of the environment to which the structures are exposed. Better quality control in the selection of materials and processes on site can control the problems related to the concrete system. Deterioration from the environment can be classified as physical or chemical. Abrasion, erosion, cavitation, freeze and thaw cycles etc. lead to the physical damage of concrete. Chemical deterioration of concrete is due to the ingress of chlorides, carbon dioxide, moisture, sulphates etc. leading to corrosion of the re-bars as well as degradation of the concrete. The main reasons for all concrete durability problems are the interconnected porous nature of the hydrated cement paste and the heterogeneity of concrete.

Aggressive chemicals enter into concrete due to many transport mechanisms, acting individually or in combination. Diffusion leads to the transfer of molecules or ions because of a concentration gradient. Both steady state and non-steady state diffusion happen in concrete. Fick's first law and second law are used to model these phenomena respectively.[1,2,3] Another important transport mechanism is permeation where the driving force is the pressure difference. Gases and liquids enter into the concrete by this mechanism. Permeation is governed by Darcy's law. Absorption (bulk intake of water), Sorption (intake of water due to capillary action), Adsorption (process of attachment of molecules on the surface), Migration (ionic movement due to the difference in the electrical potential), Convection (ionic transport driven by a difference in moisture content) etc. are other relevant transport mechanisms. A detailed description of the mechanisms and effects is provided elsewhere.[1,3]

Durability plays an important role in sustainable development, since deterioration of the structure will have double impact on the environment. First, all the debris go directly into the environment in one form or another and second, natural resources get depleted for new construction. Practices in the concrete industry have significant global effects, because of the volumes involved.

In the construction industry, durability is expected to be achieved through strength. But research has shown that there is no simple or unique relationship between strength and any of the durability parameters.[4,5] The key to concrete durability is the achievement of a tight, highly impermeable pore structure.[3,4] The challenge before the engineering community is to achieve durable concrete having adequate strength, which is cost

effective, environment friendly and thus sustainable.[4] The simple way towards this goal is by specifying the concrete accurately for its intended purpose. The specification should address different aspects such as service life, serviceability requirement, quantifiable description regarding serviceability requirement and failure, acceptable level of risk and possible extent of maintenance.[6]

Through this paper, an attempt has been made to review the development of concrete durability specifications. The international developments in this area followed by the scenario prevailing in India are reviewed. The codes related to concrete are also discussed. Further, the specifications for certain specific major infrastructure development projects in India are assessed. The shortcomings of the current system and the need for increased research in this area are emphasized.

International developments

Richardson presented a review on the development of the concrete durability design concept in his book "Fundamentals of durable reinforced concrete".[6] In the past, the cement content and w/c specified to achieve a particular strength was believed to be adequate for durability. This led to the approach known as "All-encompassing Prescriptive Approach". "The National Durability Grade Concept" developed in United Kingdom in the early 1980s was able to link durability and impermeability. That step was a milestone in the journey towards achieving durability in concrete construction. The major shortcoming of this concept was that the exposure conditions were categorized on the basis of environment and not on specific deterioration mechanisms. The development of European standard EN 206 was able to overcome this shortcoming.[7]

The environmental exposure classification system proposed in EN 206 considers the mechanisms leading to deterioration of concrete such as risk of reinforcement corrosion, effects of carbonation, chloride ingress, freeze/thaw, chemical attack etc. specifically. Durability is specified by putting limiting values of concrete composition. This approach is known as "Deterioration Specific Prescriptive Approach". Another important approach to achieve durability in concrete construction is the "Durability design method and performance testing". Durability design involves consideration of relevant deterioration mechanisms and estimation of expected service life of the structure.

According to Andrade et al., there are three categories for verification of durability.[8] The first one is the deterministic approach, which is the prescriptive approach followed by almost all the current codes based on the ''deemed-to-satisfy'' rules. The second category is known as semi-probabilistic approach. In this case, the minimum life time is assured through performance based tests, but still the time to reach a particular limit state is not explicit. The third category is the fully probabilistic approach, in which probabilistic models having explicit time elements are developed for the calculation of aggressive ingress.

While there are numerous proponents of the probabilistic approach, several shortcomings have also been identified. According to Gullikers, in many cases mathematical models lead to unrealistic predictions of the thickness of concrete cover.[9] The designers should be aware about the assumptions and limitations of the mathematical models. The inputs to mathematical models should be based on the data obtained from the actual structures. This underlines the fact that there should be very good correlation between the parameters obtained from accelerated laboratory tests and those from real structures.

The concept of performance specification, developed in the late 1990s, is a promising solution to the durability related problems of concrete. This is based on the performance criteria defined for the constructed structure. The performance can be anything related to concrete such as appearance, load carrying capacity, durability, stiffness, operability, and maintainability.[10] According to the National Ready Mixed Concrete Association (NRMCA), USA, "Performance specification is a set of instructions that outlines the functional requirements for hardened concrete depending on the application. The instructions should be clear, achievable, measurable and enforceable. Performance specifications should avoid requirements for means and methods and should avoid limitations on the ingredients or proportions of the concrete mixture". To promote the concept of performance specification, NRMCA started the P2P (Prescriptive to Performance) initiative movement. A detailed description regarding the strategies of this movement can be found in the NRMCA website.[11]

Many countries like the USA, Canada, South Africa etc. have been experimenting the concept of performance specification for more than a decade and results from the field are promising.[12-14] A number of conferences and workshops have been conducted on this topic, the latest one being the conference on Performance-based Specifications for Concrete at Leipzig, Germany

Table 1. Comparison of the durability related clauses in Indian codes

Code	Organisation	Highlights
IS 456 :2000	Bureau of Indian Standards	• 5 general exposure environments – Mild, Moderate, Severe, Very Severe and Extreme • Limits on minimum cement content, maximum water cement ratio and minimum grade of concrete for different exposures • Limits of chloride and sulphate content of concrete • Nominal cover to concrete based on exposure condition • Specific durability issues addressed : Abrasive action, freezing and thawing, exposure to sulphate attack, ASR, presence of chlorides and sulphates, concreting in seawater and aggressive soils • Inspection and testing: Compressive strength test • NDT to assess properties of concrete in structures: Ultrasonic Pulse Velocity, Rebound hammer, Probe penetration, Pull out and Maturity tests
IRS 1997	Ministry of Railways	• For severe, very severe and extreme environments, suitable coating for the structural elements are recommended • Water Permeability Test specified in the same code is mandatory for all RCC/PSC bridges under severe, very severe and extreme environments; limit for the depth of penetration of moisture is 25 mm for all cases
IRC 112 :2011	Indian Roads Congress	• Durability is "deemed to be satisfied" by the requirements of materials for the exposure conditions, which are modified from IS 456 • Additional provision for specific mechanism of deterioration such as corrosion of reinforcement, sulphate attack, alkali-silica reaction and frost attack • Anticipated service life of 100 years is specified • For a design life of 50 years or less, the minimum cover can be reduced by 5 mm • Regarding the tests, the code says "there is no specified test method for durability which can be completed within a reasonably short time" • For HPC, Rapid Chloride Permeability Test (ASTM C 1202) and Water Permeability Test (DIN 1048 part 5) or Initial Surface Absorption Test (BS 1881 part 1) can be specified • Upper limits for total charge passed in RCPT for the exposure conditions such as severe (1500 Coulombs), very severe (1200 Coulombs) and extreme (800 Coulombs) conditions are provided.
MOST / MoRTH	Ministry of Surface Transport/ Ministry of Road Transport and Highways	• Tests and standards of acceptance: cube compressive strength, chloride and sulphate content, density of fresh concrete and hardened concrete, permeability tests • Water permeability test on cylindrical specimen is specified (Section 1716.5) • The maximum permissible depth of penetration is 25 mm
Guidelines for the use of HPC in bridges	Ministry of Railways	• The clause on durability says that one of the main characteristics influencing the durability of concrete is its impermeability to the ingress of water, oxygen, carbon dioxide, chloride, sulphate and other potentially deleterious substances. Impermeability is governed by the constituents and workmanship employed in making the concrete • The acceptance tests specified - Compressive Strength, Rapid Chloride Ion Permeability test (ASTM C-1202 or AASHTO T-277), Water Permeability test as per DIN: 1048 Part 5-1991 or Initial Surface Absorption test as per BS:1881 Part 5 • The permissible value of chloride- ion permeability is 800 Coulombs. The permissible values in water permeability and surface absorption test shall be decided taking into account the severity of the exposure conditions

in June 2011. In India, awareness about performance specifications was first created by the Indian Concrete Journal through a special edition in 2005. In spite of such initiatives, the concept has not become prevalent in India. The subsequent sections will analyse the reasons, and also present cases where durability has been specified in construction projects.

Present status of the Indian construction industry

The organised Indian concrete industry is considered to be the third largest in the world.[15] Even though not at the same pace as the western countries, the Indian concrete industry is changing rapidly from the traditional on-site operations to Ready Mixed Concrete (RMC). Advantages of RMC make it easy to achieve more durable and sustainable concrete.

Construction has very intense impact on the GDP and overall economy of the nation.[16] Construction industry in the country is growing at a fast pace, primarily in the areas of infrastructure development such as roads, airports, power stations, ports, bridges etc. The infrastructural investment is 9.95 % of GDP during the Twelfth Five Year Plan. This is estimated to be equivalent to Rs. 65 lakh crores as per current prices.[17] It also emphasises the importance of durable structures to be constructed as we are using the country's valuable resources.

Review of durability related clauses in major Indian codes

The Indian Standard IS 456 2000 for plain and reinforced cement concrete is the prevalent code of practice for concrete construction in India.[18] Indian Railway Standard IRS 1997, Code of practice for concrete road bridges IRC 112-2011, MOST or MoRTH (Ministry of Surface Transport or Ministry of Road Transport and Highways) specification, Guidelines for the use of HPC in bridges are the other standards being referred to in major construction projects in addition to IS 456.[19,20,21,22]

All the codal requirements are prescriptive in nature. Table 1 provides a summary of the durability related clauses in the different Indian codes.

Review of durability related clauses in some major Indian infrastructural development projects

The clauses related to durability in some major infrastructural development projects in India are compiled in this section. The projects covered are Metro

Table 2. Comparison of the durability related clauses in some major Indian infrastructural development projects

Project	Clauses related to durability
Chennai Metro Rail	• Codes referred to : TNPWD specifications 1996/2002 / relevant IS Code / MOST/MoRTH Specifications • Automatic weigh batching or RMC • Mandatory Test - Cube compressive strength test • Additional Test - Permeability test for concrete as per IS: 3085-1965, Section 1716.5 of MOST Specification and DIN 1048 • Fly ash is being used for all concrete works except for Pre-stressed concrete works
Hyderabad Metro Rail	• For all the main structures, permeability test on concrete sample is specified • No other details or acceptance criteria regarding the permeability test are given
Kolkata Metro Rail	• Codes referred to : relevant IS Code / MOST/MoRTH Specifications • Automatic weigh batching or RMC • Mandatory Test - Cube compressive strength test • Additional Test - Permeability test for Concrete as per IS: 3085-1965, Section 1716.5 of MOST Specification and DIN 1048 • Limiting value of water penetration depth when tested as per DIN is less than 25 mm
Four-laning of Highways; Two–laning of Highways	• Codes specified: IRC:21, MoRTH Specifications (Normal concrete) ; IRC:SP:70, IRC:21, (High Performance Concrete) • Acceptance criteria for concrete as per Clause 302.11 of IRC:21

Rail Specification of Chennai, Hyderabad and Kolkata as well as Four Laning and Two Laning projects of National Highways.[23 to 27] The salient features of the corresponding specifications are described in Table 2.

Critical evaluation of the clauses regarding durability from the codes and specifications

The specification of the projects gives reference to different standards at different places. In addition to Compressive Strength Test, other tests specified are Water Permeability Test (IS 3085:1965, Section 1716.5 of MOST Specification and DIN 1048 Part 5), Rapid Chloride Permeability Test (ASTM C1202/ AASHTO T277) and Initial Surface absorption Test (BS: 1881 Part 5). Rapid Chloride Permeability Test addresses the chloride penetration at a given potential difference while the other tests attend to water permeability. Gas permeability is not dealt with in any of the test methods. The test method specified for water permeability is not clear. It gives reference to many standards. Limiting value for water permeability test is specified (25 mm) only in some cases. This is found to be very random. The test methods specified should be in tune with the exposure condition.

The specification regarding RCPT also needs clarity. The arbitrarily chosen limiting value for RCPT (e.g. 600 Coulombs for Chennai Metro Specification) is impossible to achieve in a concrete that contains only Ordinary Portland cement. Such a low RCPT value is possible when fly ash (at 30 - 35%) or slag (at 40 - 50%) or silica fume (at 5-10%) are used as cement replacements. There is no specification regarding the age of testing also. For mixes which contain mineral admixtures, the durability tests need to be conducted at 56 or 90 days, instead of 28 days.

Present exposure classifications do not adequately address the relevant durability issues. Prescriptive requirements are insufficient to ensure the durability in structures as durability in structures is largely dependent on the concreting process, the curing procedure etc. Another noticeable inadequacy is that the anticipated life or design life is not specified for the structure.

Points to ponder

People have been concerned about the durability of concrete structures for decades. Many studies have been done to understand the mechanisms leading to concrete deterioration. The concept of performance specifications attracted much discussion and has proven to be worthwhile from the experience in other countries. Countries such as US and South Africa are very much advanced in durability related tests and specifications. Lack of specific test methods to address the prevalent deterioration mechanisms have been the major hindrance in adapting performance specifications.

In spite of its large size, the peculiarities of Indian construction industry such as less mechanization, labour intensive nature and use of unskilled labourers etc. hinders it from keeping up with the pace of with international developments. However, in the present day, there is an increasing demand for RMC because of the requirements of larger volumes of concrete and faster speed of construction and the change from site-mixed concrete to RMC has helped to achieve quality and durability in some ways.

Many in industry experts feel the need for an integrated code for concrete construction. They would like it to be adequate for all general types of construction. In this way, some of the discrepancies of the current specifications can be eliminated. For example, maximum cement content specification is different in IS 456 and IRC 112. When the specification refers to both codes, confusion arises. Further, the code should give guidelines to concrete making materials, fresh and hardened properties as well to long term durability of concrete.

The durability related specifications, both in the standards and in particular projects are random. A better understanding of the deterioration mechanism in the Indian subcontinent, relevant test methods and end values are needed.

The gap between "lab-crete" and "real-crete" is very wide in our country. To ensure the quality of construction on site and to incorporate penalty clauses for non-conformance, the best solution is performance specification, which is beneficial both to the contractor and the client.

Further, current prescriptive requirements are inadequate to address the use of a variety of mineral and chemical admixtures, as these affect most of the properties of concrete in both fresh and hardened states. Workability, workability retention, compatibility between cement and superplasticiser, compressive strength development, later age strengths, setting time, resistance to ingress of aggressive chemicals, are some of the examples. The use of performance specifications would pave the way for efficient implementation of chemical and mineral admixtures in concrete, make concrete construction more sustainable.

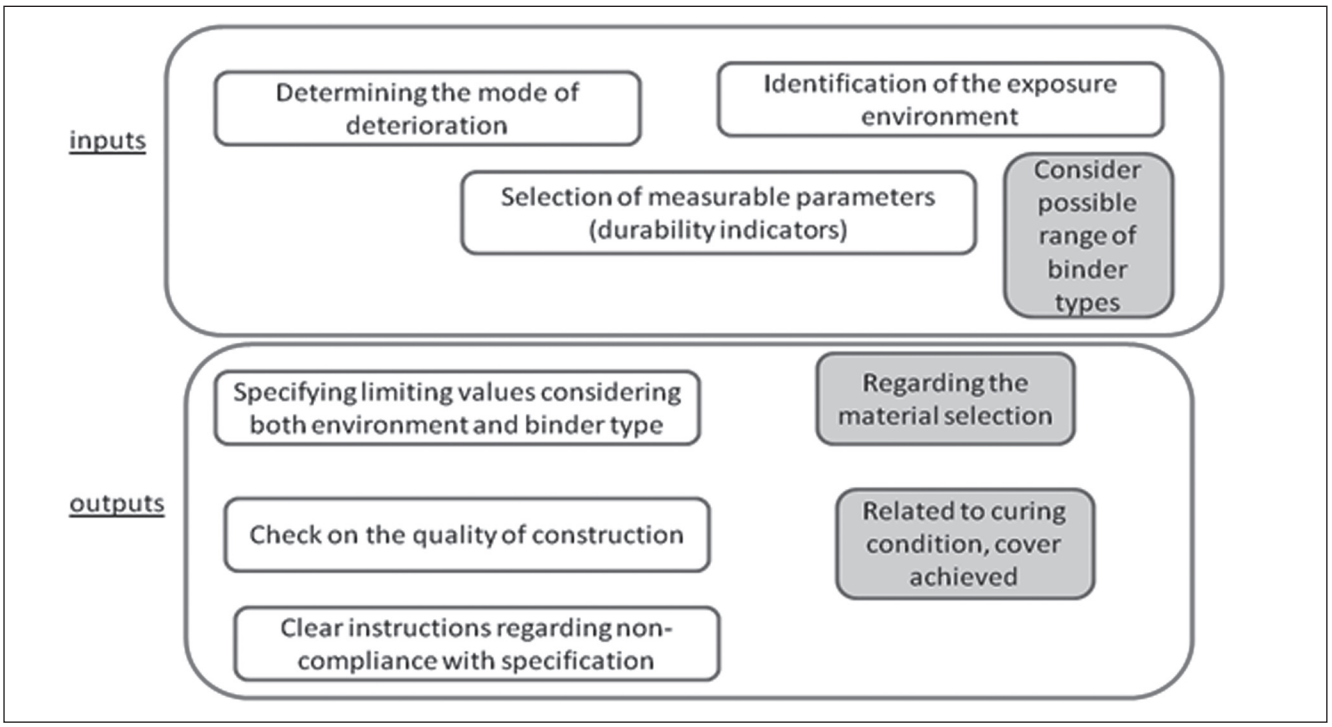

Figure 1. Process of developing performance specification [28]

Towards durability design for concrete construction in India

This section gives an insight into the processes involved in the development of performance specifications and the challenges before Indian concrete industry towards the achievement of this goal. Figure 1 presents a framework for the development of performance specifications proposed by Alexander et al.[28]

It shows that the process of developing performance specification needs a clear understanding of the mode of deterioration to the concrete structures under a particular exposure condition. Based on these factors, suitable measurable parameters known as durability indicators, need to developed. This step should consider all possible binder types and their combinations. This process would generate the following outputs. The first one is a specification regarding the limiting values of durability indicators considering both environment and binder types, which will help in selecting proper materials for concrete. The second one is a check on the quality construction related factors such as curing condition, cover achieved on site etc. Finally, it will give clear instructions regarding steps that need to be taken when the specifications are not matched.

The following section indicates the challenges before the Indian concrete industry towards the goal of achieving performance specification.

Challenges in achieving performance specification

Clear understanding of the deterioration mechanism

There are different causes of deterioration of reinforced concrete structures such as corrosion of reinforcement bars due to carbonation or chloride ingress, freezing and thawing action, sulphate attack, alkali aggregate reaction, etc. In the case of chemical deterioration process, the aggressive chemicals reach concrete or steel due to different transport mechanisms. More than one transport mechanism can operate together in many cases. Therefore, a clear understanding of the deterioration mechanism in a particular service environment is needed.

Need to revise the existing environmental exposure classification system

The existing environmental exposure condition classification in IS 456:2000 is vague. This needs to be modified based on the deterioration mechanism.

Two proposals for the change in the definition of the exposure classes along with prescriptive requirements on concrete ingredients have been presented earlier.[29,30] These proposals need to be discussed in the concrete community to enable a quick adaptation into the codes.

Identification of the test methods and parameters

There are a number of test methods available which deal with different parameters pointing towards durability. These are well-compiled by various authors and agencies.[31-33] Deep scientific understanding of the test methods and the addressing transport mechanisms along with the parameters obtained are required.

Limiting values for durability parameters

Limiting values of the durability parameters from the identified test methods need to be arrived at specific to the Indian conditions along with all possible binder combinations.

Incorporating role of mineral admixtures

Clear understanding of the distribution of carbonated and chloride-bound products in the microstructure in mixes with mineral admixtures is lacking.[34] Study of the microstructure evolution by microscopic analysis is needed at this stage.

Service life modeling and design based on the measured parameters

Service life prediction models point towards the full probabilistic approach of durability. Apparent diffusion coefficient obtained by solving the Fick's second law of diffusion is used by almost all the existing service life prediction models. Suitability of incorporating other durability parameters in service life prediction models needs to be assessed. Moreover, improvements in the existing models are required for incorporating the effects of different mineral admixtures.

Conclusion

This paper explains the movement of the concrete industry from traditional prescriptive to the performance specifications. It also highlights how durability of concrete is being outfitted in the current codes and some major construction projects in India. The possibilities and challenges for the development of performance specification as well as a fully probabilistic design based on durability aspects are dealt with in detail.

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B.S. Dhanya holds an M.Tech in Structural Engineering and Construction Management from Kerala University. She is an Assistant Professor in Civil Engineering at Rajiv Gandhi Institute of Technology, Government Engineering College, Kottayam, Kerala. She is currently a Research Scholar under QIP at Department of Civil Engineering (BTCM Division), IIT Madras. Her areas of interest are concrete durability, microstructure, repair and rehabilitation of structures and structural design.

Dr. Manu Santhanam holds a PhD in Civil Engineering from Purdue University, USA. He is a Professor at IIT Madras, Chennai. He also has some industrial experience in a construction chemicals company and his research interests include special concretes, cement chemistry, durability and non-destructive evaluation.

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