Why Performance-based Specifications for Concrete?

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Abstract

The paper presents a broad overview of performance-based specifications. It briefly describes the concrete industry scenario in India and the current practice of specifying concrete. It is argued that the nature of concrete produced in India has undergone major transformation in recent years. While the use of ready-mixed concrete from commercial facilities or captive plants has increased steeply, the organized concrete industry has started using a variety of mineral and chemical admixtures in concrete. As a result, the age-old prescriptive specifications based on old practices may no longer be appropriate and hence there is a need to change over from prescriptive to performance specifications. The paper provides a few definitions of performance specifications and highlights their advantages. The basic elements of performance specifications such as pre-qualification, sampling, testing methods, development of acceptance criteria and the bonus-penalty system are briefly described. It is suggested that some pilot projects demonstrating the benefits of performance specifications may be taken up in India in the near future.

Introduction

On a large number of small-volume concrete construction jobs in India, concrete was till recently specified in terms of nominal mixes. The fourth revision of IS 456: 2000[1] restricted the use of nominal mixes to concretes of grade M20 and below. However, the tendency to convert the designed mixes of grades higher than M20 and into equivalent proportions of volumetric mixes in a typical volume-batched, site-mixed concrete job still continues. The quality and uniformity in quality of such concretes are always doubtful and the whole process may not prove to be cost-effective.

Fortunately, with the liberalization of the Indian economy and emphasis on the development of physical infrastructure, the concrete construction scenario in India — especially in urban India — has undergone welcome transformation in the recent years.

The demand for higher speed of construction, especially for residential and commercial housing, flyovers, roads, etc. in metropolitan and other big cities of India necessitated adoption of mechanized and semi-mechanized techniques of construction. The need for large volumes of concrete as well as faster speed of concrete construction was felt. This was conducive for the development of ready-mixed concrete (RMC).

Concrete Industry Scenario

The first commercial RMC facility in India was set up in Pune in 1992 and was quickly followed by establishment of similar facilities in Mumbai, Bangalore and other places. Today, RMC is available as a commercial commodity in every metropolitan and many other large cities of the country. During the past decade, the ready mixed concrete industry in India registered an impressive growth, barring of course the set back during 2007-2009.

It is reported that RMC is now available commercially in more than 50 cities of the country. Although there are no reliable estimates available about the penetration of RMC, some experts guesstimate that total concrete produced from commercial RMC facilities was of the order of around 25 million m^3 in 2010-11. In addition to this, a large number of captive RMC facilities have mushroomed in many big cities, catering to big and medium projects in housing and infrastructure. Although their numbers far exceed those of the commercial batching plants, it is believed that concrete production from these facilities may not exceed those from commercial batching plants. Further, big construction companies and contractors, who are involved in numerous infrastructure works involving construction of roads, highways, airports, ports, power stations, hydro-electric projects, etc. have set up numerous batching and mixing plant facilities at different job sites. Again, there are no reliable estimates of concrete produced from such captive plants. However, based on the cement consumption figures, experts guesstimate concrete production from these facilities to be of the order of some 35-40 million m^3 in 2010-11. Thus, the overall concrete production from the organized sector of concrete industry would be to the tune of 85-90 million m^3 in 2010-11. A comparison of concrete production figures from different countries given in *Table* 1 reveals that the organized Indian concrete industry is the third largest concrete industry in the world.

How Concrete is Specified Currently?

Although the use of modern plant and equipment in the production, delivery and placement of concrete has increased in India, this has not matched improvement in the concrete specifications. On a majority of projects, we still continue to specify concrete in the age-old manner. The ghost of site-mixed concrete still haunts us in our day-to-day practice and it gets reflected in concrete specifications. Thus, while the use of modern plant and equipment has helped us in achieving higher speed of construction; we are yet to take full advantage of the improved quality of concrete from the use of new and sophisticated tools.

On a majority of the construction jobs, concrete is specified by its 28-day compressive strength and slump at pour location. A mention is also made regarding the use of pump or otherwise during placement. Other mechanical properties of concrete, namely, flexural strength, tensile strength, modulus of elasticity, shrinkage, creep, etc are hardly specified.

The provisions for durability are sometimes specified, but only occasionally. For example, depending upon the so-called arbitrary definitions of exposure classes, some owners/consultants do specify the limiting values of minimum cement content, maximum w/b ratio, and cover to reinforcement. There is usually resistance on the part of consultant and architects to specify the use of supplementary cementitious materials such as fly ash, ground granulated blast-furnace slag, etc. Even when the use of these materials is allowed, there is a limit on the percentage replacement of cement by these materials, much lower than even the code-specified values.

Besides durability, the current Indian codes do not fully address the issue of sustainability. For example, the so-called "deem-to-satisfy" approach of codes do not specify service life for structures, neither what constitutes the end of service life.

Further, the codes provide only broad guidelines for different construction processes involving transportation, placing, compaction and curing of concrete. From production to final placement, concrete changes hands many times. Unless all personnel involved in these operations are properly trained and educated, the desired quality of concrete will not be obtained.

Although there is a separate code on ready-mixed concrete, namely IS 4926:2003[2], it is unfortunate that cognizance of this code is not taken in many contracts. Even when using RMC, on many occasions, reference is made to only IS 456, the BIS specification on plain and reinforced concrete.

Changing Nature of Concrete

In recent years, a number of advancements have occurred in the technology of concrete. Concrete is no longer a mixture of merely cement, aggregates and water. It has now become a mixture of admixtures! Now-a-days, concrete produced from ready-mixed concrete facility incorporates more than one variety of mineral and chemical admixtures.

A recent ACI report ITG 8-R-10[3], sums up the major changes that have occurred in recent years as follows:

- Portland cement is not the only cementitious material
- Compressive strength is not the only criteria in developing acceptable mixes for a project
- Water content and aggregate size are not the main factors influencing slump
- W/c ratio is not the only factor influencing permeability.

With the use of a variety of mineral and chemical admixtures, designing of concrete mixes has become more complex. This is because the use of different admixtures affects most of the properties of concrete in its fresh and hardened states, such as workability and workability retention, compatibility between cement and superplasticizer, compressive strength development, later age strengths, setting time, resistance to ingress of aggressive chemicals, etc.

It is difficult to write prescriptive specifications that encompasses these developments. Further, in recent years, it has been observed that many structures constructed strictly following prescriptive specifications have necessarily not performed well, especially with regards to its durability. There is thus an urgent need to for a change in specifications from prescriptive to performance.

What is Performance Specifications?

A number of leading organizations and professional bodies from the Western countries have been working on the development of performance specifications for concrete. They have tried to define performance specifications in different manner. Some of the definitions are given below:

ACI's Innovative Task Group (ITG)[3]

> "Performance specification defines required results, the criteria to judge performance and verification methods without requirements for how the results are to be obtained."

Canadian Specification CSA A 23.1[4]

> "A performance concrete specification is a method of specifying a construction product in which the final outcome is given in mandatory language, in a manner that the performance requirements can be measured by accepted industry standards and methods. The processes, materials or activities used by the contractors, subcontractors, manufacturers and material suppliers are then left to their discretion."

National Ready Mixed Concrete Association (NRMCA), USA[5]

> "It is a set of instructions that outlines the functional requirements for hardened concrete depending on applications. The instructions should be clear, achievable, measurable and enforceable."

Advantages of Performance Specifications

Some of the major advantages of performance specifications are listed as below:

- Performance specifications clearly defines end-result requirements and owner's expectations
- Concrete mixes are optimized and field operations performed to ensure that owner's expectations are met
- Specifiers focus on what is needed, rather than on how to get it
- There is a focus on concrete behavior and characteristics that really matter
- Benefits can be obtained from the use of :
    - Unique materials
    - Material combinations
    - Technology expertise
    - Knowledge of local materials and conditions
- By concentrating on end results, performance specifications will foster innovations
- More durable product lead to lower life cycle costs and hence to enhanced sustainability

The crux of the performance specifications is that the performance characteristics are described in clear, quantitative and unambiguous manner so that performance can be properly evaluated. It is essential that reliable and repeatable test methods are used to evaluate performance characteristics along with performance compliance limits that take into account the inherent variability of each test method. The success of performance specifications depends upon the ability of producer-contractor team to correlate choices of materials, mixtures and construction techniques to the required characteristics so that projects can be planned and bid, risks and costs can be assessed and materials and construction operations adjusted to comply with performance requirements.

Risks and Responsibilities

Under prescriptive specifications, problems in end-result concrete are frequently blamed on producer and/or contractor. This is because the responsibilities are not defined in a clear-cut manner. Under performance specifications, responsibilities of owner, contractor and producer are clearly defined. Shared responsibilities are also clarified. However, it is essential to understand

the over-riding principle — responsibilities and authorities must be congruent! This means that if contractor and concrete producers are responsible for performance, they should have freedom to develop products meeting owner's requirements. The usual requirements of minimum cement content, maximum w/b ratio, limitations on the percent replacement of SCMs, etc. should not be insisted upon the producer.

In this context, the Canadian specification, CSA A23.1/A23.2 has listed out responsibilities of different stakeholders, i.e. owner, contractor and producer in a clear and transparent manner. This is detailed in *Table* 2.

Elements of Performance-based Requirements

The basic elements of performance-based requirements are:

- Pre-qualifications
- Sampling
- Testing methods
- Development of Acceptance Criteria

Pre-qualifications

The salient requirements of pre-qualification include:

- Characterization of all raw materials involving testing and certification
- Certification of RMC facility to ensure that all process control parameters are in order
- A system for review and approval of proposed concrete mixes involving lab trials or assessment of previously-produced mixes

Sampling

- Random sampling
- Point of sampling
- Frequency of sampling

Testing Methods

- Only the reliable and standardized tests should be used.
- There should be an agreement between the producer and contractor on the tests to be conducted and their frequencies.
- The agreement should include where the tests will be conducted and how the results will be interpreted.

Acceptance Criteria

Factors to be considered while developing acceptance criteria

- Variability of materials and sampling
- Managing risks
- Setting acceptability limits
- Actions when acceptance criteria are not satisfied

Bonus-Penalty System

Under performance specifications, the main task of the owner's team is to define end results in quantitative terms, specify acceptance criteria and the tests and their frequency and establish the range of acceptability. The latter will include the adoption of Bonus-Penalty system. A strong Bonus-Penalty system will encourage the contractor to build a level of quality into the structure that is commensurate with payment.

The owner will offer full freedom to the contractor-producer team to design, produce and place concrete. It is believed that allowing the concrete producer-contractor team to employ their specialized skills and expert knowledge will lead to innovations and will finally result in achieving economy for the owner.

Conclusion

The system of performance specifications represents advancement over the age-old prescriptive specifications. Some countries in the Western world have already started using the performance-based specifications on some of their projects and sufficient experience is now available in the adoption of the new system. In India, the organized concrete industry is growing fast. At this juncture it will be appropriate to undertake some pilot projects demonstrating the benefits of performance specifications.

References

1. IS 456: 2000, Plain and Reinforced Concrete- Code of Practice (Third Revision), (Reaffirmed 2005), p. 100.

2. IS 4926: 2003, Ready-Mixed Concrete- Code of Practice (Second Revision), 2003, p. 18.

3. ACI ITG-8R-10, Report on Performance-based Requirements for Concrete, Reported by ACI Innovation Task Group 8, American Concrete Institute, 2010.

4. CSA A23.1/A23.2 Concrete materials and Methods of Concrete Construction/Test Methods and Standard Practices for Concrete, Canadian Standards Institution, Canada

5. Bickley John, Hooton, R D and Hover, K C, Preparation of a Performance-based Specification for Cast-in-Place Concrete, RMC Research Foundation, National Ready Mixed Concrete Association, USA.

Table 1: Production statistics from leading concrete producing countries

Country	*Production/annum, 10^6 x m^3*	
	2007*	2010*
USA	315	270
Italy	77.4	73.2
Turkey	43.3	69.6
Spain	87.6	69.0
France	45.0	44.1
Germany	40.8	41.0
U.K.	25.6	20.5
INDIA (estimated)	50.0	90.0 (2010-11)

* Note: Above figures, excepting those from India, are based on ERMCO statistics.

Table 2: Responsibilities defined under performance specifications of Canadian code CSA A23.1/A23.2

Owner	Contractor	Producer
1. Required structural criteria including strength at age 2. Required durability criteria including class of exposure 3. Additional criteria for durability, volume stability, architectural requirements, sustainability and any other owner performance, prequalification or verification criteria 4. Quality management requirements 5. Whether concrete producer shall meet certification requirements of industry certification program 6. Any other properties they may be required to meet the owner's performance requirements.	1. Work with producer to establish to establish concrete mix properties to meet performance criteria for plastic and hardened concrete, considering the contractor's criteria for construction and placement and owner's performance criteria 2. Submitting documentations demonstrating owner's pre-qualification performance requirements are met 3. Prepare and implement a QC Plan to ensure that the owner's performance criteria will be met and submit documentation demonstrating owner's performance requirements have been met	1. Certify that the plant, equipment and all materials used in concrete comply with the requirements of this standard 2. Certify that the mix design satisfies the requirements of this standard 3. Certify that the production and delivery of concrete will meet the requirements of this standard 4. Certify that the concrete complies with the specified performance criteria 5. Prepare and implement a QC Plan to ensure that the owner's and contractor's performance requirements will be met 6. Provide documentation to verify that the concrete producer meets industry certification requirements 7. Submit documentation to the satisfaction of owner demonstrating that the proposed mix design will achieve the required strength, durability and performance requirements