Report on Performance-Based Requirements for Concrete

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This report discusses the differences between performance and prescriptive requirements for concrete, and provides information on developing performance requirements as an alternative to the current prescriptive requirements in codes and specifications. Performance-based requirements allow the contractor and concrete producer to be more innovative in concrete applications, providing an element for sustainability of concrete construction. The essential elements of a performance-based requirement are reviewed, which include the desired performance characteristics, sampling and testing procedures to verify these characteristics, and acceptance criteria. Because acceptance criteria are crucial elements of effective performance specifications, factors to consider in developing criteria that distribute risks to the owner and members of the construction team are discussed. Considerations for implementing performance-based requirements on a project are presented and development of performance-based requirements for durability emphasized. Alternative performance-based requirements are proposed for the prescriptive durability requirements in ACI 318.

Keywords: acceptance criteria; bonus-penalty provisions; building code; durability; in-place tests; performance specification; prescriptive specification; quality assurance; responsibility; sampling; sustainability; test methods.

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ACI 329R-14 supersedes ACI ITG-8R-10 and was adopted and published December 2014.

CHAPTER 1—INTRODUCTION

1.1—Background

1.1.1 *Prescriptive and performance specification*—A specification is an explicit set of requirements to be satisfied by a material, product, system, or service (ASTM 2013). In the concrete construction industry, the primary types of specifications are materials specifications and construction specifications. The former provide minimum requirements for composition and properties, and the latter form part of the contract between owner and contractor. Specifications can be of the prescriptive or performance type, or they may include components of each. A prescriptive specification for concrete focuses on the properties and composition of raw materials; mixture proportions; batching, mixing, and transport of fresh concrete; and a range of construction operations from placing to curing. Prescriptive specifications rely on observed or implied relationships between the details specified and the desired final, in-place, or end-product concrete performance. Under a prescriptive specification, the desired end-product performance may or may not be described. A performance specification, however, defines required results, the criteria to judge performance, and verification methods without requirements for how the results are to be obtained. An alternative name used by some agencies is end-result specification (ERS). The Federal Highway Administration (FHWA) has invested considerable resources to promote the use of performance-related specifications (PRS) in its projects (FHWA 1998). The PRS approach is intended to ensure the completed product will perform as specified.

Prescriptive and performance specifications have been in existence as long as code requirements and specifications for concrete have existed. For example, in 1910, the National Association of Cement Users (NACU), the forerunner of ACI, adopted its "Standard Building Regulations for Reinforced Concrete" (NACU 1910). These regulations provided alternatives for concrete strength:

> Concrete composed of materials meeting the requirements of these regulations, mixed in proportion of one part of cement and six parts of aggregate (fine and coarse), shall develop a compressive strength of 2000 pounds per square inch in 28 days when tested as 8-in. diameter cylinders 16 in. long under laboratory conditions of manufacture and storage, using the same consistency as is used in the field. When the proportion of cement is increased, using the best quality of aggregates, an increase may be made in all working stresses proportional to the increase in compressive strength at 28 days, as determined by actual tests, but this increase shall not exceed 25 per cent."

Thus, it is seen in this early document governing concrete construction, there were elements of prescriptive and performance requirements.

In 1936, ACI adopted the "Building Regulations for Reinforced Concrete (ACI 501-36T)," which served as a basis for many provisions that are still in use (American Concrete Institute 1936). ACI 501-36T permitted a performance-based alternative to the prescriptive water-cement ratio (w/c) requirements for different design strengths. Alternative mixture proportions were permitted by prequalifying a mixture on the basis of test data correlating strength to w/c. Four different w/c values had to be tested, and the w/c approved for production was that value corresponding to a compressive strength that was:

a) 20 percent greater than the design strength when design strength was less than 2500 psi (17 MPa)

b) 15 percent greater than the design strength when design strength was 2500 psi (17 MPa) or above

These requirements are the forerunner of today's required strength based on standard deviation of historical data. Once the proposed mixture was approved, no substitutions in materials were permitted without additional tests.

For durability, ACI 501-36T stated that "All concrete exposed to the weather shall have a minimum ultimate 28-day compressive strength of not less than 3000 lb per sq. in." According to ACI 501-36T, design professionals were responsible for on-site inspection of construction, including maintaining records of "the quality and quantity of concrete materials, the mixing and placing of the concrete, and the placing of the reinforcing steel."

Today, the responsibility for site verification of concrete production has shifted away from the licensed design professional toward the concrete producer. The licensed design professional, however, is still responsible for review or approval of the submitted mixture ingredients and proportions.

Other changes in the concrete industry since these early codes were written include:

a) Recognition that concrete strength is not the only characteristic considered in developing an acceptable concrete mixture for a project

b) Portland cement is not the only cementitious material

c) Water content and aggregate size are not the only factors that influence slump

d) The *w*/*c* is not the only factor influencing permeability

A variety of admixtures have emerged to impart characteristics to a concrete mixture that are otherwise difficult or impossible to attain by varying only the basic ingredients of cement, aggregate, and water. Chemical admixtures and supplementary cementitious materials (SCMs), such as pozzolans and slag cement, affect factors including air content, air-void characteristics, workability, setting time, bleeding, rate of strength gain, long-term strength, and resistance to fluid penetration. In addition, combinations of the various cementitious materials and admixtures may or may not be mutually compatible.

It is difficult to write prescriptive specifications that make use of these developments while, at the same time, avoiding their pitfalls. It is evident that evaluating concrete durability is more difficult than evaluating strength. The increasing demand for improved concrete durability and growing complexity of concrete mixture proportioning add importance to the debate of prescriptive versus performance-based requirements.

Interest in performance-based requirements is fueled by the changes in practice that have evolved to enhance concrete durability and sustainability. For example, consider the high-performance, low-permeability concretes required to ensure durable structures under severe exposures. Such mixtures often use portland cement along with one or more SCM, may use one or more type of admixture, including a corrosion inhibitor, and may incorporate at least three sizes of aggregate. Developing an acceptable mixture requires experience with specific materials, including recognition that traditional relationships, such as those between workability and water content and those between strength and *w*/*c*, are affected by a variety of factors, such as types and amounts of admixtures and SCMs. In addition, the compatibility of admixtures with cementitious materials should be investigated (Taylor et al. 2006). To ensure durability, the risk of cracking should be controlled. Curing of concrete characterized by rapid surface drying, rapid setting, and a high shrinkage potential requires special attention.

The reason performance-based requirements should be considered when prescriptive requirements have been the mainstay of the concrete industry is that more is demanded of concrete, and using a strictly prescriptive specification makes it difficult to take full advantage of the wide range of available options under a performance specification.

1.1.2 *Prescription to performance initiative (P2P)*—In 2002, the Research, Engineering and Standards Committee (RES) of the National Ready Mixed Concrete Association (NRMCA) embarked on an initiative called P2P—"Prescription to Performance"—to introduce performance specifications as alternatives to traditional prescriptive specifications (Bickley et al. 2006a; Hover et al. 2008). There was concern that prescriptive specifications can hinder concrete producers from providing mixtures that optimize available materials while meeting the owner's needs. Similarly, overly prescriptive requirements may stifle the concrete contractor's capability to use innovative methods that support sustainability principles (1.5) and produce an acceptable product.

The P2P steering committee commissioned a project to review state-of-the-art industry practices internationally on performance specifications (Phase I) and to explore alternatives to existing prescriptive specifications for concrete (Phase II). Background information in this report relies heavily on the first P2P publication (Bickley et al. 2006a). The second report, which is referred to as the *P2P Phase II Report*, is a guide in writing performance-based requirements as alternatives to the prescriptive requirements in current ACI reference specifications (Hover et al. 2008). The Phase I report is described in greater detail in Chapter 2. The P2P project team observed that while there was an almost universal interest in performance, primarily for durability and sustainability, there were few performance specifications. A majority of the reviewed international standards defined exposure conditions for each country, prescribing limits for concrete mixtures that, on the basis of past research or experience, would result in the desired durability. The review revealed there is an almost universal use of supplementary cementitious materials (SCMs), such as fly ash, slag cement, and silica fume, either as separate additions or incorporated in blended cements. The specification documents assumed statistical quality control was used to ensure consistent conformity to the owner's requirements.

Authors of the *P2P Phase I Report* (Hover et al. 2008) observed that, depending on the perspective of the stakeholder, the term "performance specification" can have different meanings. Due to the wide array of options and valid interpretations, it is imperative the term be carefully defined in any given context. Parties could agree in principle to execute work under the performance specification umbrella while having widely differing views about mutual expectations.

The *P2P Phase I Report* (Hover et al. 2008) concluded that the lack of reliable, consistent, and standardized test procedures for evaluating concrete performance is frequently cited as a major barrier to the adoption of performance-based requirements. Most tests available are performed under standardized conditions, serving as indicators of relative performance rather than measures of actual performance in service. Relative to tests conducted under prescriptive standards, performance tests can be expensive, are time consuming, and lack desired precision. The short time

available to respond to a bid request and to start construction creates difficulties for a concrete producer required to develop a performance mixture and perform prequalification testing.

1.1.3 *Establishment of ITG-8R*—The Strategic Development Council (SDC), one of three organizations operating under the ACI Foundation, has embraced the need for performance-based requirements in the concrete industry. The SDC's mission is to facilitate the advancement of concrete technology by providing a forum for predicting and prioritizing key challenges facing the concrete industry, assisting ACI in timely adoption of innovative technologies and best practices, and providing a framework for consortia-directed development programs leading to commercialization. The SDC adopted a strategy for accelerated technology acceptance by identifying industry-critical technologies and applying resources to address these areas. In 2004, SDC identified the move from prescriptive to performance-based requirements as an industry-critical technology area and created an accelerated technology implementation team to address the need. After further evaluation, however, the team chose the innovation task group (ITG) mechanism of ACI to address the issue. The ACI Technical Activities Committee (TAC) evaluated the application for an ITG and approved the creation of ITG-8. The mission of ITG-8 was to develop a report on performance criteria and test methods for concrete materials that could be used in codes and specifications. In 2010, ACI published ITG-8R-10. This report is based on the ITG-8R-10 document with some revisions.

1.2—Objective and scope

The objectives of this report are as follows:

a) Provide an introduction to performance specifications and discuss how they compare with prescriptive specifications

b) Discuss the essential features of performance specifications

c) Discuss how performance-based requirements can be used as alternatives to traditional prescriptive requirements

With respect to the third objective, the performance-based tests and criteria discussed in this report are intended to serve as examples and should not be interpreted as specification requirements. Design professionals should determine what is applicable to their projects in accordance with established codes and local practice.

Chapter 1 is an introduction to performance-based requirements and compares them with prescriptive requirements. Of special importance are the differences in the responsibilities of various parties under performance-based and prescriptive requirements. Chapter 2 provides definitions used in this report.

Chapter 3 discusses the three principal elements of performance-based requirements:

1. Required performance characteristics
2. Sampling and testing methods
3. Acceptance criteria

A summary is provided of common and less common test methods used to confirm performance requirements are met. Emphasis is placed on test methods available for assessing the durability potential of a concrete mixture.

Chapter 4 discusses acceptance criteria, reviews key consideration factors, and discusses actions that may be taken when the acceptance criteria are not met.

Chapter 5 addresses implementation of performance-based requirements on new projects. The various means of enhancing communication between affected parties are reviewed. There is discussion on the use of bonus-penalty provisions in contract documents. Finally, the technical challenges to implementation of performance specifications are discussed.

Chapter 6 reviews prescriptive durability requirements of ACI 318 and ACI 301 as opportunities to develop performance-based requirements. Examples are provided of performance-based requirements as alternatives to prescriptive durability requirements (ACI 318). These examples are based on the *P2P Phase II Report* (Hover et al. 2008).

Chapter 7 provides a summary of the report and lists future activities to facilitate implementation of performance-based requirements.

This report is not intended to provide a comprehensive set of performance-based requirements that can be incorporated directly into contract documents as alternatives to traditional prescriptive requirements.

It is important to recognize that a performance specification does not preclude the use of some prescriptive requirements when that is the most practicable approach for developing a workable project specification. Likewise, largely prescriptive specifications sometimes include some performance-based requirements. These hybrid specifications have worked well and are expected to continue to do so in the future. This report does not suggest that prescriptive specifications should be replaced with performance specifications. There are many cases where prescriptive specifications are the best solutions for all stakeholders. Rather, Committee 329 takes the position that because performance specifications encourage innovation, the industry should advance toward establishing performance-based alternatives to prescriptive requirements.

1.3—Performance-based requirements

As mentioned previously, a prescriptive specification defines the materials and methods of concrete placement. In contrast, a performance specification for concrete starts with the end state in mind, and describes the required quality characteristics of the end product, leaving the details about materials selection, proportioning, and construction means and methods up to the party bound contractually to complying with the specifications. Under a performance specification, the concrete construction team, which includes the concrete producer, general contractor, placement contractor, and the concrete contractor, is responsible for selecting and proportioning materials and conducting construction operations that will result in the required performance. Prescriptive specifications state how to proportion and install the concrete such that, if done in accordance with instructions, the end results will be satisfactory. Performance specifications, however,