Performance-Based Specifications for Concrete

A Focus on Innovation, Quality and Customer Satisfaction

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Moving from prescriptive specifications to performance-based specifications is the next logical step in the evolution of the concrete construction industry. Concrete producers incorporate extensive quality control and product development programs to design concrete mixes for any application. Concrete contractors are building faster and more economically than ever before. Unfortunately, many project specifications are prescriptive in nature and stifle innovation, increase cost and decrease quality. Performance-based specifications can result in innovative products and construction processes, higher quality, reduced cost and satisfied customers.

Since the early days of the ready mixed concrete industry in the 1920s, technological advances, production capabilities and practices of concrete producers and contractors have evolved into an advanced science. Back then, the technical expert was the person who ordered concrete by mixture proportions. Today, modern ready mixed concrete production facilities have technical experts that participate in the standards development process, and laboratories that incorporate rigorous quality control and product development programs to design concrete mixtures optimized for performance for any application. Concrete contractors employ the latest forming and placement methods to build faster and more economically than ever before. Concrete construction is now much more complicated than before, and the expertise that exists with the various parties involved needs to be leveraged to ensure that the owner gets a high quality structure with a long projected service life.

Unfortunately, many project specifications continue to remain prescriptive in nature as a holdover from earlier days. These prescriptive limitations stifle innovation by limiting the types and quantities of ingredients, material proportions and construction methods. Prescriptive clauses in specifications for concrete are based on age-old understanding, experiences or empirical relationships of the basics of concrete technology that continue to be regenerated from project to project. In many cases, additional clauses are invoked that cause significant inherent conflicts of intent, performance attributes and assignment of responsibility. Prescriptive specifications are often overly conservative, which can lead to higher costs and unexpected negative results… ultimately leading to unsatisfied customers.

A shift from prescriptive specifications to performance-based specifications is the next logical step in the evolution of the concrete industry. Performance-based specifications address requirements for mechanical and functional properties of the concrete. The results are verifiable through measurement or testing to assure the product meets the desired requirements. The assigned responsibilities for achieving certain objectives are clear. Finally, performance based specifications are free of process limitations such as mixture proportions and construction methods. Performance-based specifications encourage partnering within the construction team, innovative products and construction methods in conjunction with rigorous quality management systems that lead to superior products and satisfied customers.

What is a Prescriptive Specification?

A prescriptive specification is one that includes clauses for means and methods of construction and composition of the concrete mix rather than defining performance requirements. Many times intended performance requirements are not clearly indicated in project specifications, and the prescriptive requirements may conflict with the intended performance.

Many project specifications include a minimum cement content and maximum water-cementitious materials (w/cm) ratio in addition to minimum compressive strength requirements. For each set of materials there is a unique relationship between the strength, cement content and w/cm ratio. A different set of materials has a different relationship as illustrated by the plots of compressive strength versus w/cm ratio for the three different mixes in *Figure 2*. A 0.45 w/cm ratio for these three mixtures have strengths of 3800, 5000 and 6000 psi respectively. **Clearly specifying a w/cm ratio requirement does not ensure that a certain strength will be achieved**. In fact, a common conflict is a strength requirement that does not match a w/cm ratio, resulting in strength results that significantly exceed the required strength while also being potentially highly variable.

The engineer may be tempted to say that this is not new information. The reason why he or she wanted a limitation on the

Figure 1: Performance-based specifications foster innovation and acceptance of new technology such as high-strength concrete and self-consolidating concrete for high-rise

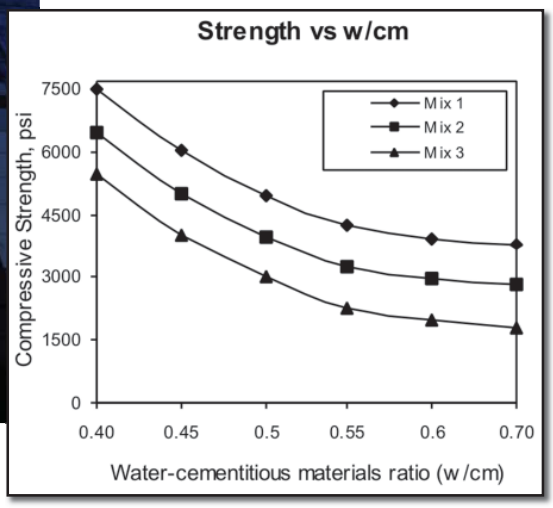

Figure 2

maximum w/cm was to ensure durability. It is true that a lower w/cm generally leads to lower permeability and better concrete durability, but concrete durability is also substantially influenced by a host of other factors. Type and content of cementitious materials play important roles. Different combinations of portland cement and supplementary cementitious materials (SCM) such as fly-ash, slag, silica fume and other pozzolans can drastically affect permeability.

The four different mixes shown in *Figure 3* have different chloride ion penetrability (as measured by the ASTM C 1202 test) and a commonly used measure of permeability at the same w/cm ratio, ranging from very low permeability for the ternary mix (portland cement plus two SCMs) to very high permeability for the portland cement only mix. Even though a producer furnishes a mix at 0.45 w/cm ratio, there is no guarantee that the mix will have low permeability to water and deleterious salts. Although the graph shows only chloride ion penetrability test results, the same is true for other concrete durability problems such as alkali silica reactions (ASR) and sulfate attack. A low w/cm of 0.45 may not assure the owner that the concrete will be resistant to chloride ion penetration, ASR or sulfate attack. Two distinctly different concrete mixtures can be used to comply with a specified w/cm ratio, one with a high cementitious materials content and another that was optimized at a lower cementitious materials content using chemical admixtures. These mixtures will possess quite different performance characteristics, where one might surmise that the mixture with the high cement (paste) content can potentially increase the drying shrinkage, heat of hydration, creep and susceptibility to cracking.

In summary, a low w/cm is a fundamental factor that influences concrete performance. But as its relationship to these properties

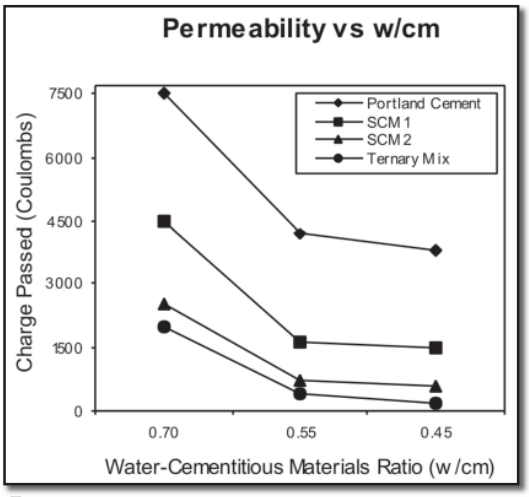

Figure 3

Figure 4: Engineers have experimented with performance-based specifications for high performance concrete used in bridge construction with the objective of designing structures with 100-year life.

is unique to the materials employed, it can neither ensure a required strength or provide good durability, or ensure satisfactory performance requirements such as low shrinkage. The same argument can be extended to minimum cementitious content requirements. A minimum cementitious content can neither ensure the required strength or required durability. Requiring low w/cm and minimum cement content may have been an effective means of controlling concrete quality in the olden days. But in recent times, with the widespread use of mineral and chemical admixtures, this is no longer true. Another case in point is that there is no reliable method of verifying compliance with a specified maximum w/cm ratio or minimum cement content at the jobsite. So, why should a prescriptive specification that cannot be measured be used in the first place? This raises an interesting question. What can an engineer who wants to ensure adequate strength and durability do in this situation?

In our view, the answer is simple and straightforward. Just specify the performance requirements for the project such as strength, durability etc. This way the engineer gets the desired performance, and the producer is in the best position to optimize the mixture to attain those performance levels with the local materials.

Prescriptive specifications also potentially lead to higher costs to the owner for several reasons: mixtures not optimized cost more, and prescribing mixture ingredients may not afford the characteristics needed for constructability, causing changes, fixes/repairs and delayed schedules. Further, they potentially restrict necessary changes in mixture proportions to accommodate variability in materials, construction methods and seasonal temperature variations. The bidder with the lowest overhead—which usually means lowest investment in quality control, research and development—is often the one that can bid the lowest and profit the most at the lowest bid. An engineer might think he/she has established a level playing field with aprescriptive mix, but in fact could be facilitating low quality. For this reason, engineers often revert to more prescriptive specifications that are extremely conservative (over-designed) to compensate for low quality leading to higher costs. If the engineer specifies the desired performance and relies on the expertise of the concrete contractor and concrete producer to deliver an optimized mix, it can often be delivered at a lower ultimate cost with higher quality to the project.

What is a Performance Specification?

A performance specification is a set of instructions that outlines the characteristics of the plastic concrete for constructability, functional requirements for hardened concrete depending on the application and aspects of the construction process that are necessary but do not restrict the innovation of the concrete contractor. The instructions should be clear, achievable, measurable and enforceable. For example, the performance criteria for interior columns in a building might be compressive strength only, since durability is not a concern. Aspects such as heat for prevention of thermal cracking (heat of hydration), modulus of elasticity and creep might also be important. Conversely, performance criteria for a bridge deck or parking garage might include limits

on permeability and cracking since the concrete will be subjected to a harsh environment, while strength may not be the critical factor for its prolonged service life.

Performance specifications should also clearly specify the test methods and the acceptance criteria that will be used to verify and enforce the requirements. Some testing might be required for pre-qualification and some might be for jobsite acceptance. The specifications should provide flexibility to the contractor and producer to provide a mix that meets the performance criteria in the way they choose. The contractor and producer will also work together to develop a mix design for the plastic concrete that meets additional requirement for placing and finishing, such as flow and set time, while ensuring the performance requirements for the hardened concrete are not compromised.

Performance specifications should avoid requirements for means and methods, and should avoid limitations on the ingredients or proportions of the concrete mixture.

The general concept of how a performance-based specification for concrete would work is as follows:

- There would be a qualification and certification system that establishes the standards for concrete production facilities and possibly the people involved.
- The project specification would clearly define the functional requirements of the hardened concrete.
- Producers and contractors would partner to ensure that the right mix is designed, delivered and installed.
- The submittal would not be a detailed list of mixture ingredients, but rather a certification that the mix will meet the specification requirements including pre-qualification test results.
- After the concrete is placed, a series of field acceptance tests would be conducted to determine if the concrete meets the performance criteria.
- A clear set of instructions outlining what happens when concrete does not conform to the performance criteria.

What are the Challenges?

There are many challenges to implementing performance-based specifications. Currently, there are no accepted model performance specifications in the United States that can be used as guides for developing performance-based project specifications. Most building codes and model specifications for concrete, including ACI 318 and ACI 301, are predominantly prescriptive in nature.

Some engineers have experimented with performance-based specifications on high-performance concrete, especially for bridge applications where durability and long life are critical. These applications are at the cutting edge of concrete technology, using a wide range of supplementary cementing materials and admixtures along with innovative construction techniques to minimize permeability and cracking. The intent is to extend the life of structures beyond 100 years—which is significant in light of the harsh environments in which these structures reside.

Having performance specifications for all types of concrete will improve the overall quality of concrete construction. Some engineers may feel that if they do not specify minimum cement content or maximum w/cm, or aggregate gradation or volume of a fly ash there is no means to control the quality of concrete. But this is not the case. Final performance will still be measured, and the concrete accepted, only if the performance meets the requirements of the specifications. Some other engineers feel that concrete producers do not have the knowledge to furnish performance-based concrete of the quality that they desire. The purpose of a qualification system affords that comfort. Prescriptive specifications can still exist as an alternative in these situations.

Led by the National Ready Mixed Concrete Association (NRMCA), the ready mixed concrete industry has established the P2P Initiative to promote a shift from traditional prescriptive specifications to per-

formance specifications for concrete. P2P is an acronym for Prescription to Performance specifications. The Research, Engineering and Standards (RES) Committee of NRMCA formed a steering committee in October 2002 to develop a strategic roadmap for the P2P Initiative. The P2P Steering Committee has collaborated with industry stakeholders, including concrete contractors, material suppliers, engineers and architects to develop a set of goals and strategies to implement performance-based specifications.

The primary goal of the P2P Initiative is to improve quality by moving away from prescriptive requirements to those based on performance criteria. Strategies for the P2P Initiative include:

- Allow performance specifications as an alternative to current prescriptive specifications through education and communication
- Leverage the expertise of all stakeholders in the construction industry to improve quality and reliability of concrete construction
- Assist architects and engineers to address concrete specifications in terms of performance requirements, allowing concrete suppliers and contractors flexibility on the details of concrete mixtures and construction means and methods
- Elevate the performance level and credibility of the ready mixed concrete industry through training and certification
- Foster innovation and acceptance of new technology at a faster pace through research and development

NRMCA is developing a model performance specification that outlines the performance requirements, submittal requirements, prequalification requirements and acceptance criteria. The model specification identifies consequences of non-performance and a resolution mechanism. In addition to design requirements, the model will include a mechanism whereby contractors can add construction requirements for installation and delivery.

NRMCA is also conducting laboratory research to demonstrate the effectiveness of performance-based specifications. Concrete specimens will be prepared using typical prescriptive specifications such as those in ACI 318 and tested for a variety of attributes, including strength, workability, shrinkage and durability. The results will be compared to specimens prepared using performance-based specifications.

NRMCA also realizes performance specifications will only be successful if ready mixed concrete producers are qualified to design and deliver concrete under the new specifications. They are developing a new quality management standard that will provide assurance to the purchaser that a concrete producer is capable of designing, producing and delivering concrete that is consistent with the performance requirements. The standard will establish guidelines for ready mixed concrete production facilities, equipment, personnel, management, testing, mix performance data and documentation.

Although the challenges are many and the effort involved will be extensive, NRMCA feels the change is necessary to ensure continued growth and improvement of the concrete industry. Improved quality, innovation and customer satisfaction are at the core of the P2P Initiative.▪

To get involved, visit **www.nrmca.org/P2P** or contact Lionel Lemay at **LLemay@nrmca.org**.

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