Performance-based specifications for concrete

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A specification is a means of establishing the requirements of the owner on the contractor for a constructed project. With the specific expertise of various contractors and product suppliers in a concrete construction project, the specification should assign the appropriate separate and joint responsibilities for compliance. Architects and design engineers are getting much more innovative with their design of space and structural elements. Concrete contractors are using many innovations and are building faster and more economically than ever before. Concrete producers incorporate extensive quality control and product development programmes to design concrete mixes for any application. However, many project specifications are prescriptive in nature and stifle innovation, increase cost and negatively impact quality. Moving from prescriptive specifications to performance-based specifications is the next logical step in the evolution of the concrete construction industry. Performance-based specifications can result in innovative products and construction processes, higher quality, reduced cost and satisfied customers.

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Since the early days of the ready-mixed concrete industry in the 1920s in the United States, technological advances, production capabilities and practices of concrete producers and contractors have evolved to an advanced state. Back then, people ordered concrete by mixture proportions. The concrete producer was a local, family-owned business with about 1 to 3 plants in a town or region.

By contrast, modern ready-mixed concrete producers have technical experts that participate in the standards development process and have laboratories that incorporate rigorous quality control and product development programmes to design concrete mixtures optimised 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, the way project specifications are written has not kept pace with this broadening knowledge. 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, mixture proportions and construction methods. Prescriptive clauses in specifications for concrete are often based on outdated knowledge or empirical relationships. In many cases, prescriptive 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 that can lead to innovative products and construction methods resulting in superior projects and satisfied customers.

Codes and specifications

Codes

A code, such as a building code, establishes minimum requirements for buildings to protect public safety. The provisions of the code ensure that the design (and to a small extent the construction process) of the building is such that it minimises the chance for loss of life. By this assumption, material and construction requirements for a specific project as written in a specification or contract should at a minimum comply with the codal requirements but can, and often should, have provisions that exceed the codal requirements and address specific local and project requirements. When adopted by a local or state jurisdiction, the code is the law and therefore subject to legal review and process.

In the US, ACI 318 serves as the building code for structural concrete. It is developed through a consensus process by Committee 318 of the American Concrete Institute. It is referenced for the most part by the model building codes, such as the International Building Code, that is then adopted wholly or with amendments, by a local jurisdiction. ACI 318 applies to buildings. Transportation agencies set the minimum requirements for transportation structures.

It is generally the responsibility of the structural engineer to ensure that the design of the structure complies with the requirements of the code and where applicable incorporate requirements in a specification such that the pertinent responsibility beyond his control is transferred to the other stakeholders, contractors and product manufacturers, charged with constructing the project.

Specifications

A specification for concrete construction is a set of instructions from the owner, typically written by a design professional as his representative, to the concrete contractor. A specification eventually forms the basis of a contract, a legal agreement, between the owner and the contractor and establishes the joint and separate responsibilities of the various stakeholders in the construction team towards achieving the objectives of the owner. For that reason the specification should be written in terse mandatory language with clear, measurable and achievable requirements.

The authors have reviewed numerous project specifications written by national and regional design firms and observe several problems that could cause unintended negative consequences and restrict the expertise of the contractor and concrete producer. Listed below are some general suggestions for improving specifications for concrete.

- Specification clauses that require compliance with industry reference documents, especially guidance documents written in non-mandatory language should be avoided. These documents discuss various options and if a specific option is needed for the project it should be written in the specification in mandatory language.
- The specification should not include a general statement requiring compliance with the Building Code. It is the design professional's responsibility to establish provisions of the code that apply to the project and write them in the specification. Do not apply code provisions to portions of structures for which they are not applicable. For example, non-structural elements such as slabs-on-grade or exterior flatwork are not governed by ACI 318.
- The specification should avoid outlining details of construction means and methods as the expertise of the contractor is stifled.
- The specification should avoid dictating details of the mixture proportions as the concrete producer's expertise is stifled. Often the contractor and concrete supplier can work out the requirements of plastic concrete for construction. For example, allow the contractor and producer to select slump and method of placement.
- State the required performance in measurable terms that are enforceable. For example, "Concrete shall have entrained air content of 5.5 percent ±1.5 percent at the point of discharge from the transportation unit when tested in accordance with ASTM C 231."
- Requiring the use of specific brands of products or equipment should be avoided, especially when reference standards or alternative equivalents are available.
- Avoid adding on requirements to a set of conditions that currently work as this can cause a different problem. Avoid making acceptance criteria more restrictive than accepted industry practice as that may not be achievable or could cost more for no associated benefit.
- Submittals prior to the start of work should be limited to documenting conformance to the specification requirements. This process can be significantly simplified from the current practice.

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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 controls on the composition of the concrete mixture such as a minimum cement content, type of cement, limits on the quantity of supplementary cementitious materials, maximum water-cementitious materials (w/cm) ratio, limits on the grading of aggregates or type used, brand of admixture and required dosage, etc. In addition, there may be requirements on compressive strength or other properties that are implied but not clearly stated in the specification. Very often, these requirements cannot be achieved based on the restrictions placed on the mixture composition. For each set of materials there is a unique relationship between the mixture proportions such as cement content and w/cm ratio and resulting strength and durability properties. Placing unjustified limitations on one or more of these parameters of the concrete mixture in a specification often contradicts the intended or implied performance.

Consider a real example of concrete for an interior building column. The specification required a 0.40 w/cm ratio, a minimum cement content of 380 kg/m^3, a maximum fly ash content of 15 percent by mass of cementitious material, a compressive strength of 28 MPa, and a maximum slump of 100 mm.

For this structural element the critical performance characteristic is the compressive strength and the associated mechanical properties that can be empirically related to strength. Since the column is protected from environmental severe exposures the w/cm ratio limit is not necessary for durability and the requirement for a minimum cementitious content is not needed to meet the strength requirements. Presumably, the limit on fly ash is to ensure rapid form stripping and/or rate of strength gain but this is an issue of means and methods and should therefore be avoided in the specification. The restriction on the w/cm ratio and slump will likely cause placement problems with congested reinforcement and likely result in surface defects due to difficulties with consolidation.

There are a few options that a producer might use to comply with this specification.

- One option is to start with water, estimated at 175 kg/m^3 for the target slump with the local materials and use a cementitious content of 440 kg/m^3 to meet the maximum w/cm requirement. The strength of this mixture is more likely to be in the range of 50 MPa or higher. This mixture also has a high paste content which will cause associated problems such as high heat of hydration, shrinkage, and creep. The mix will not be the most economical one because of the high cementitious materials content.
- Another option is to start with the minimum cementitious content and establish the maximum water content of the mix at 150 kg/m^3 again to meet the maximum w/cm requirement. Based on the water demand of the local materials, this mixture will require relatively high dosages of water reducing and/or high range water reducing admixtures. This mixture has a lower paste content but may not have the appropriate consistency (could be more sticky) for proper placement. The strength is likely to be in the range of 45 MPa.
- If the only requirement was strength, say at 3 days for contractor's form stripping requirement and at 28 days for design requirements, the producer might choose to optimise the mixture by controlling aggregate quantity and grading, minimising the paste content and provide the necessary mixture consistency, possibly using self consolidating concrete, and achieve the necessary form stripping and design strength. A concrete mixture targeting an average strength of about 32 MPa can be designed with a cementitious content of about 275 kg/m^3, with possibly up to 25 percent fly ash. This mixture will have the lowest paste content that will have improved performance with respect to heat of hydration, shrinkage and creep. If designed for proper consistency without the restrictions on the w/cm, cement content, or slump, it will also result in a better surface finish.

Prescriptive provisions such as w/cm ratio or cement contents are fundamental factors that influence concrete performance but are unique to the materials employed, which can vary widely from region to region

The example illustrates how prescriptive provisions in a specification might result in widely different concrete mixtures. The same example can be extended to durability properties of concrete. The typical surrogate for durability is to set a low w/cm ratio limit. This is a key parameter of a concrete mixture that controls several properties including permeability. Lower permeability typically leads to more durable concrete. However as stated earlier for strength, the relationship between w/cm and permeability is unique to the set of materials used. One can get a wide range of permeability of concrete at a 0.40 w/cm ratio with different mixtures, especially with the use of modern-day chemical admixtures and supplementary cementitious materials.

In summary, prescriptive provisions such as w/cm ratio or cement contents are fundamental factors that influence concrete performance but are unique to the materials employed which can vary widely from region to region. They are factors that should be attended to by the person developing the mixture and should not be limitations in the specification, unless of course the building code requires it.

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 and establish the criteria for conformance to the requirements. This way the engineer gets the desired performance, and the producer is in the best position to optimise 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 optimised cost more, and prescribing mixture ingredients may not afford the characteristics needed for constructability, causing defects that must be repaired or replaced 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 a prescriptive mix, but in fact could be facilitating low quality. For this reason, engineers based on past experience often revert to more prescriptive limitations that are extremely conservative (over-designed) to compensate for low quality.

If the engineer specifies the desired performance and relies on the expertise of the concrete contractor and concrete producer to deliver an optimised mix, it can often be delivered at a lower in-place cost with higher quality to the project.

What is a performance specification?

A 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.

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 of hydration for prevention of thermal cracking, modulus of elasticity and creep might also be important. Conversely, performance criteria for a bridge deck or parking garage slab, besides design strength, might include limits on permeability and cracking since the concrete will be subjected to a harsh environment. Strength will generally 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 the necessary 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 mixture proportions such that the plastic concrete that meets additional requirements for placing and finishing, such as flow and set time, while ensuring the performance requirements for the hardened concrete are not compromised. Flexibility on mixture composition is also necessary to accommodate source variability of ingredient materials and seasonal aspects that impact ambient conditions during construction.

Performance specifications should avoid provisions on 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 the people who design concrete mixes. This establishes the credentials necessary to deliver performance-based concrete.
- 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.

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- 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 will outline what happens when concrete does not conform to the performance criteria.

It is the design professional's responsibility to establish the appropriate measurable and enforceable performance criteria for concrete to assure the owner that he gets what he wants. It is a design function to select appropriate performance measures and criteria for expected service life of the structure. There will be a transfer of responsibility associated with performance specifications. The concrete producer and the contractor, will be responsible for meeting the performance criteria established by the design professional. But that will be the limit of their responsibility. With that responsibility comes the authority to do the right things to comply with the specification. In a prescription specification, on the other hand, the producer and the contractor are solely responsible for complying with the prescriptive limitations as defined and not for any intended or implied performance that they do not have control over. In practice, however, the producer and contractor are often assigned responsibility for problems even with prescription specifications.

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, especially for durability requirements. Attempts are underway to review and revise current code and specification provisions that adversely impact innovation and performance. Also lacking is the availability of reliable and rapid test methods that measure durability. Research is underway to address this situation too.

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 minimise 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 situations where no qualified producers exist.

P2P initiative

In one of several efforts to move towards performance-based specifications, the National Ready Mixed Concrete Association (NRMCA), who represents the ready-mixed concrete industry, has established the P2P initiative to promote a shift from traditional prescriptive specifications to performance specifications for concrete. P2P is an acronym for "Prescription to Performance" 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, and
- Foster innovation and acceptance of new technology at a faster pace through research and development.

Conclusion

The evolution to performance based specifications is critical to the success of the concrete construction industry in competing with alternative building materials and in the sustainable construction initiatives. Performance specifications will only be successful if the stakeholders in the concrete construction process are knowledgeable and cognisant of the needs and capabilities of the others. All stakeholders including architects, engineers, contractors and producers must partner to ensure a successful project. Although the challenges are many and the effort involved will be extensive, the change is necessary to ensure continued growth and improvement of the concrete industry.

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