# Performance-Based Specifications for Shotcrete Contracts

By Phil T. Seabrook

Performance-based specifications (P-BS) for concrete projects have recently been introduced to the North American construction industry. They have been in use in Europe and elsewhere for some time. To the best of the author's knowledge, they have not seen significant use for shotcrete work. Because shotcrete is simply an alternate method of placing concrete, however, there does not appear to be any reason why shotcrete P-BS should not evolve. This article discusses the potential for the use of P-BS in shotcrete contracts and notes some realities in that process.

The original North American impetus for P-BS came from the ready mixed industry that saw such specifications as a method of protecting proprietary technology embedded in their mixture proportions. Recently, the American Concrete Institute (ACI) has been active in developing the base for such specifications. An ACI Innovation Task Group (ITG) has recently published ITG-8R-10, "Report on Performance-Based Requirements for Concrete."[1] ACI also devoted three major sessions at the ACI Spring 2011 Convention to this development. Some information presented herein is from those sessions.

## Nature of P-BS

There are a number of definitions for P-BS, but ITG-8R-10[1] states:

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

In addition, ACI notes that P-BS are "alternate" forms of a specification.[1]

It should be recognized that the use of P-BS is an evolving process. Much of this evolution is currently being driven by various government authorities.

Most prescriptive specifications now contain some performance elements. An example is the requirements for compressive strength. Some authorities have presented hybrid specifications containing a mixture of prescriptive and performance requirements.

Those currently using P-BS are unified in stipulating that a fundamental requirement is trust between the parties of the contract. Related to this, there has to be shared risk among these parties. They then list these needs:

- A designer/specifier who has sufficient technical knowledge to define the end product and how to test it;
- An owner who is prepared to enter into a contract where trust is a base and is also prepared to share in risks, presumably with the benefit of a more cost-effective and/or longer service-life structure;
- A specification that is clear, achievable, measurable, and enforceable;
- Sufficient lead time so that the necessary qualification tests can be conducted. Further, appreciation that the up-front costs for qualification may be high;
- Contractors and shotcrete mixture suppliers who have the ability to interpret the specification and respond in a technically sound form;
- A functional quality management system (QMS). This is also an evolving technology with North American contractors and suppliers. The contractor has to have a responsible and functional quality control program, and the owner then should have a complementary quality assurance program. The contractor's quality management plan should require approval by the owner;
- Acceptance criteria. This has to be based on a statistical approach, perhaps a Lot system where, for example, a Lot could be defined as each day's placement;
- A process to address the situation if the acceptance criteria are not met. This normally would include dispute resolution methods;
- Service life should be the base of the P-BS requirements. This leads to the use of modeling. There are now available models for service life but they mostly focus on chloride ion ingress and may not relate to a particular project's shotcrete environmental exposure; and
- A bonus/penalty provision. This is stated by current users to be a necessary incentive for the contractor.



With regard to bonus/penalty, this is obviously a challenge and begs the question, "If P-BS is of such a claimed benefit, why is an incentive necessary?" Authorities who shared their experience with P-BS stated that the contractors all achieved bonus. Some authorities admit to setting the bar low so that a positive experience on initial contracts would be readily achieved, then the bar could be raised later. It is interesting to reflect on how bonus/penalty could be worked into a shotcrete contract. As for concrete, however, bonus could simply result from meeting the performance criteria.

The matter of service life needs further exploration. It is now common for authorities to require 75 years for infrastructure projects. Then there is the challenge of defining how much maintenance is included in the calculation of life. The writer is not aware of any shotcrete projects where service life was specified or assessed by the designer. However, there is no reason why shotcrete could not be modeled in the same way that concrete is currently treated. Given that much of today's shotcrete contains silica fume, and all service life models of concrete with silica fume show great advantages, the service life of shotcrete could be long with proper design and construction. Interestingly, according to Marc Jolin of the University of Laval, Quebec, QC, Canada, the university is now undertaking a project to evaluate the service life of various common shotcrete mixtures.

To model a shotcrete mixture, it would be necessary to shoot a panel of the proposed mixture and core samples from it. The samples would be tested for diffusion and other transport properties required for the model. These properties would then be fed into the model with parameters of the structure and the projected service life would result.

## Claimed Benefits of P-BS

The fundamental justification for P-BS in concrete construction is that it opens the door for innovation by the contractor (and concrete supplier) and now possibly a shotcrete subcontractor. This is certainly true. Unfortunately, in some cases, this has translated into opening the door to construction or material choices that are simply cheaper and not necessarily in the interest of concrete performance. The justification assumes that the parties are capable of taking advantage of the benefits of P-BS through their technical abilities.

Innovation results in the use of materials and construction systems that are more suited to the contractor's system. Contractors can take advantage of new technology—the use of new admixtures being an example. By definition, this should also be more cost effective. Proponents claim that P-BS leads to sustainability, which comes from the more efficient use of materials and possibly extended service life.

Sustainability is of current interest to ASA and the concrete industry, and it is discussed in a number of issues of *Shotcrete* magazine, such as the Spring 2011 issue.[2] Of the suggested sustainability features of shotcrete in *Shotcrete*, the formwork savings would probably be most important here, although schedule acceleration would also be of interest to most owners.

As an example of the present stage of P-BS evolution, one authority put out tenders for a concrete infrastructure project based on both prescriptive and P-BS specifications. Tendered costs were similar, and the authority concluded that the contractors in its area were not ready to take advantage of P-BS.

## Acceptance Criteria

Those using P-BS all acknowledge that establishing acceptance criteria is a major challenge. Included in the criteria must be the required sampling plan, typically defining some form of core extraction. Such plans would be fundamental parts of the QMS.

Consider the example of acceptance of concrete compressive strength. Current codes require sampling at the end of the concrete truck chute for concrete acceptance (also sometimes for wet-mix shotcrete). For P-BS, the sampling for the owner's purposes would likely be in-place, which would leave testing of as-delivered concrete to the contractor's or ready-mixed supplier's quality control. This is a logical separation of responsibilities, but it would be necessary to define those responsibilities in a contract between the contractor and supplier. Would failure of compressive strength be the result of the mixture, the consolidation in shooting, or the subsequent curing?

Following are examples of some acceptance criteria that might be considered for shotcrete work (Table 1). In all cases, there is a challenge to define the "what if" the acceptance criteria are not met. This is where the penalty provisions have been used in some contracts. Many of these criteria measured by testing could not be confirmed until the shotcrete is months old.

For most tests, it is necessary to define the required average value and also some minimum/maximum. This accounts for the within-test variations and isolated local lower-quality shotcrete. The spread between average and minimum/maximum can be varied with the precision of the particular test. As an example, the current ACI 318 code defines strength acceptance as having the average strength of cores greater than 85% of the specified strength with no single core less than 75% of that strength.

**Table 1: Acceptance Criteria for Shotcrete**

| Property | Criteria | Comments |
|---|---|---|
| Dimensional tolerance | Easily defined. ACI 117 is a guide. The main interest may be shotcrete thickness. | Need to define the type, amount, and frequency of measurement. |
| Surface finish | Common criteria are those in prescriptive specifications. Hard to quantify as performance. | No problem for as-shot. |
| Compressive strength | Criteria well established. Would probably require in-place sampling as well as panels for quality control. | Only an indirect measure of durability. |
| Absorption | Acceptance criteria well established and recognized in the industry. | Can be used as both a qualification and quality control test. |
| Water-cementitious material ratio (*w*/*cm*) | This is currently the base for durability assessment of concrete in all codes. | Some are measuring this in the field with the microwave test. Presumably that test could be used for both wet- and dry-mix. |
| Resistance to chloride ion penetration[3] | General criteria for acceptance now available. | Test not commonly conducted on shotcrete but it could be done. Test normally conducted on concrete at 28 to 56 days or later age. |
| Diffusion, surface, and bulk | Test procedures established, but no quantified acceptance generally recognized. | Considerable research ongoing. A few authorities have used diffusion for qualification and even quality control. |
| Freezing-and-thawing resistance | Criteria for acceptance well established. | Test seldom conducted on shotcrete. Beam samples would have to be cut from shot panels. Qualification test only. Test can take 6 months. |
| Bond to substrata | Test procedure available, and there is a general agreement on achievable values for shotcrete. | Test results highly variable, requiring a large number of tests and proper interpretation. |
| Reinforcing bar encapsulation | This would have to be defined by the designer. | The use of core grades in the current ACI 506.2 standard is being discontinued for all applications except nozzlemen certification, so new criteria has to be developed. ACI 506 is addressing this. |

Note that a number of these tests would only be used for qualification of the mixture. Considerable lead time would be required to complete them. Such lead time is seldom available in most current contracts.

Also, Table 1 shows that a significant challenge in acceptance is in defining workmanship properties.

## Application of P-BS to Shotcrete Work

The requirement to use in-place samples for assessment of the end product can readily be accommodated in shotcrete.

The pending revised ACI 506.2,[4] "Specification for Materials, Proportioning, and Application of Shotcrete," has many of the elements that would be required for compliance with a P-BS contract. Examples include:

- The shotcrete industry has embraced the ACI Nozzleman Certification and most experienced shotcrete contractors can readily provide certified nozzlemen. Certifications are a normal requirement of P-BS. They are not currently available for general contractors;
- The specification will require extensive preconstruction submittals with verifiable technical content. These submittals will include items such as documented properties of the proposed mixture and possibly projected service life based on a specified service-life model; and
- ACI 506.2[4] will require the contractor to conduct quality control and the owner to do the quality assurance. This is intrinsic in P-BS.

Therefore, the shotcrete industry is already in a position to comply with some of the normal P-BS requirements.

P-BS today are normally considered only for large projects, particularly large infrastructure projects. They also require contractors and suppliers with advanced technical knowledge to design and produce the required end product.

P-BS is ideal for design-build projects because, by definition, these projects are performance-based. It is possible that increases in design-build projects will lead the development and adoption of P-BS.

## A Look to the Future

P-BS is not for all projects. Most projects, however, could benefit from hybrid specifications that combine prescriptive and performance-based specifications.

Projects where P-BS are currently being used are not those that would commonly be undertaken by shotcrete contractors, except perhaps as a subcontractor. However, there is no reason why the shotcrete portion of a large contract could not be performance-based.

This is an evolving process and, as the industry becomes more sophisticated, it is probable that some shotcrete contractors will look to P-BS to take advantage of their innovative approaches to common concrete construction challenges. Innovative uses of shotcrete can also result in substantial advances in sustainability of the final concrete structure.

## References


1. ACI Innovation Task Group 8, "Report on Performance-Based Requirements for Concrete (ITG-8R-10)," American Concrete Institute, Farmington Hills, MI, 2010, 46 pp.
2. Darnell, C., "Sustainability" column, *Shotcrete*, V. 13, No. 2, Spring 2011, p. 46-47.
3. ASTM C1202-10, "Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration," ASTM International, West Conshohocken, PA, 2010, 7 pp.
4. ACI Committee 506, "Specification for Materials, Proportioning, and Application of Shotcrete (ACI 506.2-95)," American Concrete Institute, Farmington Hills, MI, 1995, 8 pp.



***Phil T. Seabrook**, FACI, PEng, PE, is the President of his own private consulting firm, Phiz Engineering Ltd., Vancouver, BC, Canada. He has over 50 years of expertise in concrete materials, including a significant amount in shotcrete. Seabrook is a Warden of the Iron Ring for Canada, Past President of Levelton Consultants, and Past President of the Association of Professional Engineers and Geoscientists of British Columbia. A member of the American Concrete Institute (ACI), he was a founding member of the BC Chapter and served as its President. Nationally, he is a long-term member of ACI Committee 506, Shotcreting, and has been the Chair of ACI Committee 506-0E, Shotcreting-Specifications, since 1995, and serves on a number of other ACI committees. Seabrook recently received an award for 50 Years of Service from ACI. In Canada, he was Chair of the 1994 edition of CSA A23.1 on concrete. Seabrook received numerous awards over the years, including the prestigious Consulting Engineers of BC Meritorious Achievement Award and APEGBC's McLachlan Award for outstanding technical, professional, and community service contributions. Seabrook is the author of many technical papers. Recent activities include dispute resolution in construction failures and quality management for large infrastructure projects.*