Specifying for Performance

Case studies show that cooperative efforts lead to success

by Karthik H. Obla, Daniel J. Gancarz, William R. (Rusty) Owings III, Fouad H. Yazbeck, and David G. Tepke

A design professional's essential responsibility is to ensure that a completed project will attain the level of performance required by the owner. Globally imposing overly conservative requirements (for example, using the harshest environment to set the durability requirements for an entire project) will add needless cost and detract from sustainability goals. Rather, design professionals should define performance-based requirements for the concrete used in the project based on the use and exposure for specific portions. This could be accomplished using a performance specification in lieu of stating prescriptive requirements. For example, Provision 1.10.1 of ACI 318-14[1] states:

"Sponsors of any system of design, construction, or alternative construction materials within the scope of this Code, the adequacy of which has been shown by successful use or by analysis or test, but which does not conform to or is not covered by this Code, shall have the right to present the data on which their design is based to the building official, or to a board of examiners appointed by the building official. This board shall be composed of competent engineers and shall have authority to investigate the data so submitted, require tests, and formulate rules governing design and construction of such systems to meet the intent of this Code. These rules, when approved by the building official and promulgated, shall be of the same force and effect as the provisions of this Code."

The mission of ACI Committee 329, Performance Criteria for Ready Mixed Concrete, is to develop and report information on performance criteria for ready mixed concrete. This article provides summaries of four projects discussed at a session, Case Studies of Performance-Based Specifications, sponsored by Committee 329 at The ACI Concrete Convention and Exposition – Spring 2017 in Detroit, MI.

Performance is Fundamental

Performance-based specifications that meet explicit durability goals can be successfully used on different types of projects. The following sections describe four examples.

Pavement

Since 2008, the Illinois Tollway has been using performance-based specifications for concrete mixture proportions to ensure durability and sustainability while minimizing cost. A recent example, completed in 2016, was a portion of the $2.5 billion Jane Addams Memorial Tollway (I-90) Rebuilding and Widening Project, from Roselle Road to Illinois Route 53/I-290 in Schaumburg, IL.

Performance-related mixture and construction special provisions were incorporated into the contract documents, and an outreach program was implemented at the beginning of the project to ensure that the stakeholders (Tollway representatives, contractor, and concrete producer) understood and properly implemented the provisions. The performance criteria for mixture qualification included compressive strength, flexural strength, and plastic and hardened air contents. Jobsite acceptance tests for the concrete included compressive strength and plastic air content. Jobsite acceptance criteria also included edge-slump of the slip-formed pavement, pavement thickness and smoothness, and dowel alignment. Bulk resistivity testing was performed as a research effort to determine the formation factor. The formation factor may be included in future versions of the special provisions.

By using performance criteria, the Tollway allowed greater use of cementitious materials and eliminated restrictions on water-cementitious material ratio (*w/cm*). It also allowed the implementation of nonstandard aggregate gradations, thus encouraging the use of local materials. To ensure a high-quality mixture, however, prescriptive limits were still placed on specific supplementary cementitious material (SCM) contents, aggregate grading, and aggregate susceptibility to alkali-silica reaction (ASR).

The contractor chose to use a ternary cementitious material mixture with an optimized aggregate gradation. Because the selected mixture had 24% less portland cement and 15% less total cementitious material than a typical Illinois pavement mixture, the Tollway realized a lower bid price. The mixture exceeded the performance criteria and, as a result, the contractor received a bonus.

Bridge

The Christopher S. Bond Bridge was completed in 2010 in Kansas City, MO. Parsons, the engineer for the project, worked with Missouri Department of Transportation (MoDOT) officials to develop the project using design-build project delivery and a performance-based specification. To achieve the specified performance requirements, the concrete producer used mixture proportions with optimized aggregate gradations and ternary blends of cement and SCMs.

Jane Addams Memorial Tollway (I-90) Rebuilding and Widening project credits: Illinois Tollway, Owner/Engineer; Walsh Construction Company, Contractor; and Terrell Materials Corporation, Concrete Supplier

Christopher S. Bond Bridge project credits: MoDOT, Owner; Parsons Corp., Engineer; Paseo Corridor Constructors (a partnership of Massman Construction Co, Clarkson Construction Co, and Kiewit Construction Co), Contractor; and Fordyce Concrete, A Division of Ashgrove Materials Corp, Concrete Supplier

Performance criteria on the project included:

- Drilled shaft foundations—specified compressive strength of 4000 psi (28 MPa) at 56 days, low heat of hydration (158°F [<70°C] maximum per ASTM C150/C150M, "Standard Specification for Portland Cement"), and slump of 8 ± 1 in. (200 ± 25 mm) or spread flow of 26 ± 4 in. (660 ± 100 mm);
- Pylon (center vertical structure)—specified compressive strength of 7000 psi (48 MPa) at 56 days, moderate permeability (<2000 coulombs per ASTM C1202, "Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration"), ASR expansion below 0.08% at 16 and 30 days (ASTM C1567, "Standard Test Method for Determining the Potential Alkali-Silica Reactivity of Combinations of Cementitious Materials and Aggregate (Accelerated Mortar-Bar Method)"), and slump of 8 ± 1 in. or spread flow of 26 ± 4 in.; and
- Bridge deck—structural pour strips between precast panels and the deck topping with specified compressive strength of 8000 psi (55 MPa) at 56 days, low permeability (<1000 coulombs per ASTM C1202), ASR expansion below 0.08% at 16 and 30 days (ASTM C1567), pass scaling resistance (visual rating of 0-1 per ASTM C672/C672M, "Standard Test Method for Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals"), microwave oven water content test (AASHTO TP 23, "Standard Test Method for Water Content of Freshly Mixed Concrete Using Microwave Oven Drying") on each day of placement, and slump of 8 ± 1 in. or spread flow of 26 ± 4 in.

Each concrete mixture design was prequalified using laboratory tests and tested as required per the project specification from concrete placed for the structure (ASTM C1202 and C672/C672M testing every 30 days, and ASR testing every 6 months). The microwave test was required on the first load for every placement for the deck structure concrete mixture and had to be completed prior to allowing the concrete to be placed. Testing was done at the plant and the results were communicated to the team on site.

Initially, the contractor conducted quality control tests and MoDOT conducted random quality assurance (QA) tests in the field. This resulted in a lot of testing of concrete mixtures. Effective communication and sharing of information was important to keep on schedule and address any issues. The QA testing program was relaxed after passing QA test results were consistently reported. The performance specification led to significant cost savings, as the contractor was able to use lower cementitious material contents in comparison to prescriptive mixtures from MoDOT's standard specification.

Development

The 2012 project, Al Raha Beach Development – Phase 1, Abu Dhabi, UAE, involved several types of structures (infrastructure, seawalls, bridges, residential buildings, and services and utilities). The project's wide range of exposures led to the use of performance specifications to streamline production, testing, and acceptance of concrete. Another motivation was the potential for reduction of waste due to over-ordering or on-site breakdowns.

The performance requirements were two-fold, with stringent testing for mixture qualification and identity testing (mainly strength and some durability) at the time of supply. All prescriptive requirements (minimum and maximum cement contents, maximum *w/cm*, SCM types and dosage limits, and aggregate grading limits) were removed to allow mixtures to be designed as "fit for purpose." The resulting mixtures had elevated cement replacement levels to enhance service life and reduce the carbon footprint. Multiple subproject specifications were replaced with a single document that was enforced sitewide.

There was some reluctance to remove prescriptive elements completely from the specification. This was recognized early on, and some requirements (especially durability testing on site) were incorporated into the performance specifications to alleviate the concerns.

Many advantages were realized, including reduction of waste, better consistency of concrete due to the reduction of number of mixtures produced, and lower CO_2 emissions due to a high SCM content.

Steel column encasement

Lower-level columns of Hyperion Towers, North Myrtle Beach, SC, were heavily corroded. The columns support a seven-story condominium, so rehabilitation was urgent. Concrete jacketing was selected as a practical method for addressing structural concerns, and the engineer decided to use a performance specification to obtain the necessary concrete characteristics. Concrete that could adequately protect and supplement steel, while providing durability for the severe coastal environment, was needed. A team approach was used—the engineer worked with the contractor to define the QA process, including small batch testing, full-scale trials, and mockup placements.

A self-consolidating concrete (SCC) was used on the project. Some of the key mixture qualification requirements included:

- Minimum compressive strength of 5000 psi (35 MPa);
- Minimum 28-day to 7-day compressive strength ratio of 1.3;
- Maximum rapid indication of chloride-ion penetrability (RCP) of 1200 coulombs (7-day standard cure followed by 21 days at 100°F [38°C]), per ASTM C1202;
- Maximum shrinkage of 300 microstrain (7-day cure followed by 28-day drying) per ASTM C157/C157M, "Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete";

Al Raha Beach Development – Phase 1 project credits: ALDAR Properties, Owner/Engineer; ALDAR Laing O'Rourke, Main Contractor; and ALDAR Readymix, Concrete Supplier

Hyperion Towers project credits: Hyperion Towers Homeowners Association, Owner; SKA Consulting Engineers, Inc., Engineer; Heard Ratzlaff Construction, Inc., Contractor; and Ready Mixed Concrete Company, Concrete Supplier

- Maximum ASR expansion of 0.10% at 14 days per ASTM C1260, "Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method)";
- Maximum column static segregation of 10% per ASTM C1610/C1610M, "Standard Test Method for Static Segregation of Self-Consolidating Concrete Using Column Technique";
- Maximum Visual Stability Index (VSI) value of 1 per ASTM C1611/C1611M, "Standard Test Method for Slump Flow of Self-Consolidating Concrete"; and
- Minimum air content of 5% per ASTM C231/C231M, "Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method."

A level of training was required to provide relevance for the types, implementation, importance, and execution of specifications and tests. Specifications were set up such that performance characteristics were required, but prescriptive provisions were included to provide guidance on meeting performance. This allowed the construction team to price the work adequately and consult with the engineer during the mixture development phase. The SCC mixture meeting specifications included 30% Class F fly ash, 5% silica fume, optimized gradation of locally available aggregates, and shrinkage-reducing admixture, with a slump flow of approximately 25 to 28 in. (640 to 710 mm).

References

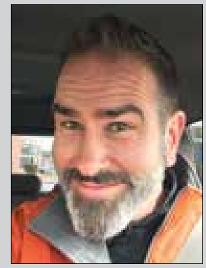
1. ACI Committee 318, "Building Code Requirements for Structural Concrete (ACI 318-14) and Commentary (ACI 318R-14)," American Concrete Institute, Farmington Hills, MI, 2014, 519 pp.

Note: Additional information on the ASTM and AASHTO standards discussed in this article can be found at **www.astm.org** and **www.transportation.org**, respectively.

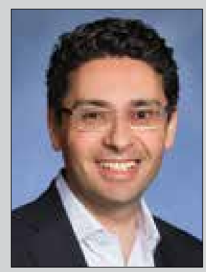
Selected for reader interest by the editors.

Karthik H. Obla, FACI, is Vice President of Technical Services at the National Ready Mixed Concrete Association (NRMCA), Silver Spring, MD. He serves on several ACI committees, including ACI Committees 201, Durability of Concrete; and 329, Performance Criteria for Ready Mixed Concrete. He is a recipient of ACI's Young Professional Achievement Award and served as President of the San Antonio Chapter – ACI. He received his BS in civil engineering from the Indian Institute of Technology (BHU), Varanasi, India, and his MS and PhD in civil engineering from the University of Michigan, Ann Arbor, MI.

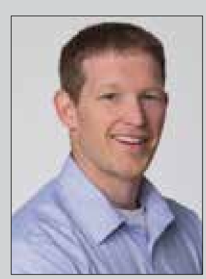
ACI member **Daniel J. Gancarz** has been with Applied Research Associates, Inc., since 2013 as an On-Site Project Engineer with the Materials Group at the Illinois Tollway. He supports design and construction reviews for materials and pavements and leads the Tollway's review and approval process of concrete mixture designs. Gancarz is a member of ACI Committees 325, Concrete Pavements, and 329, Performance Criteria for Ready Mixed Concrete. He received his BS and MS in civil engineering from the University of Illinois at Urbana-Champaign, Urbana, IL. He is a licensed professional engineer in Illinois.



ACI member **William R. (Rusty) Owings III** is Quality Control General Manager at Geiger Ready-Mix Co., Inc., Kansas City, KS. He has over 18 years of experience working in the design and construction industry, specifically with concrete related projects. He is a member of ACI Committee 329, Performance Criteria for Ready Mixed Concrete. He is also a member of NRMCA's Research and Specification Committee and Chair of the Kansas Ready Mixed Concrete Association's Technical Quality Committee. Owings is the Past President of the Kansas Chapter – ACI. He received his bachelor's of architecture from the University of Kansas, Lawrence, KS, and is a licensed architect.



ACI member **Fouad H. Yazbeck** is Technical and Commercial Director at Unimix, LLC (Universal Concrete Products Co.), Dubai, UAE, with over 20 years of experience in the concrete industry. He is a member of the ACI International Advisory Committee and Committees 130, Sustainability of Concrete; 207, Mass and Thermally Controlled Concrete; 234, Silica Fume in Concrete; and 329, Performance Criteria for Ready Mixed Concrete. He is a founding member of Lebanon Chapter – ACI and UAE-Dubai Chapter – ACI, and a member of the Beirut Order of Engineers. He received his civil engineer diploma from Saint Joseph University, Beirut, Lebanon, and MBA from ESSEC Business School, Cergy-Pontoise, France.



ACI member **David G. Tepke** is Building Solutions Group Manager and Senior Engineer at SKA Consulting Engineers Inc., Charleston, SC. He is Secretary of ACI Committee 222, Corrosion of Metals in Concrete; and immediate past Chair of ACI Committee 329, Performance Criteria for Ready Mixed Concrete. He is also a member of ACI Committees 201, Durability of Concrete, and 301, Specifications for Structural Concrete. He is a NACE International Certified Corrosion Specialist and Protective Coating Specialist. Tepke received his BS and MS in civil engineering from the Pennsylvania State University, State College, PA, and is a licensed professional engineer in several states.