Sustainable Concrete: The Role of Performance-based Specifications

Lionel Lemay[1], Colin Lobo[2] and Karthik Obla[3]

[1] National Ready Mixed Concrete Association, 1244 Crane Blvd., Libertyville, IL, 60048; PH (847) 918-7101; email: LLemay@nrmca.org
[2] National Ready Mixed Concrete Association, 900 Spring Street, Silver Spring, MD, 20910; PH (240) 485-1160; email: CLobo@nrmca.org
[3] National Ready Mixed Concrete Association, 900 Spring Street, Silver Spring, MD, 20910; PH (240) 485-1163; email: KObla@nrmca.org

ABSTRACT

Concrete is used in nearly every structure we build today, including buildings, bridges, homes and infrastructure. With greater emphasis placed on sustainability in recent years, structural engineers are faced with the challenge of meeting traditional design criteria in addition to evolving criteria that support sustainable construction. Performance-based specifications for concrete can substantially help meet this new challenge. Prescriptive requirements such as minimum cement content or maximum water to cement ratio are among many common specification requirements that can increase the environmental footprint of concrete. This paper outlines how concrete performance can be improved while lowering environmental footprint by implementing performance-based specifications.

INTRODUCTION

Sustainable concrete is difficult to define. There are many factors that can influence the way concrete is manufactured, designed, built, used and recycled that ultimately affect the environmental footprint of concrete and the structures built with concrete. Whether one is designing a high rise building, pavement, bridge, dam or warehouse, concrete is an important component used as foundation and superstructure, and these structures can have a significant impact on our environment throughout their lifecycle. Structural engineers can influence the performance and environmental impact of structures through effective design and specifications regardless of the materials being used. However, concrete is unique in that it so versatile both in terms of physical characteristics (size, shape, appearance, etc.) and mechanical properties (strength, stiffness, permeability, etc.) that structural engineers can influence performance, including environmental impacts, of concrete and concrete structures significantly through design decisions and project specifications.

INFLUENCE OF DESIGN DECISIONS

The single biggest influence an engineer can have on the environmental impacts of a structure is through efficient design. The following are several factors that affect the performance of concrete and concrete structures:

Design Loads. Every structure, at a minimum, must be designed to resist forces from gravity, service, wind, earthquakes, water, soil, fire and blast, among others. If a structure does not meet these minimum requirements it would be deemed unsafe and therefore unsustainable. Usually a structural engineer designs the structure to resist minimum loads prescribed in a building code. Alternatively, the owner can choose higher loading to resist natural disasters or other loading over and above the building code minimums. Having a structure that can resist disasters without suffering significant damage would be considered more sustainable. After all, a green building that is destroyed during a natural disaster will ultimately increase environment burden since materials in the building (structure, fixtures, furnishings, etc.) will end up in landfills and the building will be rebuilt using new materials.

Structural Efficiency. Regardless of the design loading, a structural engineer's objective is to design the structural system for optimized performance and to minimize waste. There is no point in having a concrete mixture with low environmental impact if the structural member is overdesigned by 20%. Not only can efficient design lower impact of the structural system, but it also tends to reduce impacts of other materials. For example, minimizing the depth of beams in the structure can significantly reduce the floor-to-floor heights of a building, thus leading to reduced quantity of exterior cladding and interior finishes.

Durability. A structure that needs constant maintenance results in significant environmental impact. Structures exposed to harsh environments must be designed appropriately to resist deterioration. For concrete, that usually means consideration of freezing and thawing cycles, abrasion, chlorides (from road salt or marine environments) or sulfates (contained in soil or water). A combination of good design detailing along with durable concrete mix designs can result in a durable concrete structure. Appropriate concrete cover, corrosion resistant reinforcement, low permeability concrete, effective use of supplementary cementitious materials (SCMs), chemical admixtures that improve corrosion resistance, surface coverings and crack control are all potential strategies for providing a durable concrete structure. The building code requirements for structural concrete, ACI 318, requires licensed design professionals to assign exposure classes to concrete based on the severity of the anticipated exposure of structural concrete members (ACI 318-11 2011). The code provides specific requirements for concrete mixtures to resist various levels of exposure. In most cases the requirements are performance-based, thus eliminating the need for engineers to specify additional prescriptive criteria.

Constructability. Design decisions can also affect constructability. Smaller members with congested reinforcement take more time and energy and are typically more costly to construct. A project specification that requires a minimum quantity of fly ash greater than normal use could result in delayed strength gain that could add to the construction schedule since floors might not be able to be post-tensioned within reasonable time frame or a bridge deck might not be able to open to traffic without significant delays. A project specification with a maximum limit on slag cement could result in concrete used for massive members to have high heat of hydration and result in significant cracking. A project specification that limits slump to a certain value could result in concrete that cannot be pumped efficiently or finished effectively. All of these consequences of prescriptive specification requirements could render the project unsustainable.

Energy Efficiency. Concrete buildings are typically more energy efficient than lighter framed buildings because of thermal mass. Thermal mass is a material's ability to store heat and release it over time. There are three characteristics of thermal mass. First, the time lag between peak heating and cooling loads and outside temperature peaks is greater for massive buildings. This feature can be used in buildings by delaying the need for heating or cooling energy to take advantage of off-peak demand. In an office building, that means you can delay heat gain until after everyone has gone home. Second, massive buildings have lower peak heating and cooling loads allowing for smaller more efficient heating and cooling equipment. And third, massive buildings require less overall heating and cooling energy to maintain the same interior temperatures since temperature swings are moderated.

In a research report published by the Massachusetts Institute of Technology (MIT), the effects of thermal mass were explored using life cycle analysis for a 12-story, 46,321 m^2 (498,590 ft^2) commercial building. The building was analyzed for a 60-year life for two climates, Phoenix and Chicago, and for two different structural materials, concrete and steel. The analysis demonstrated that the greenhouse gas emissions due to operational energy of the building are responsible for 95-96% of life cycle emissions. Figure 1 demonstrates that the concrete building has approximately the same embodied emissions as steel, but has lower operating emissions, which can lead to lower life cycle emissions (Ochsendorf 2011).

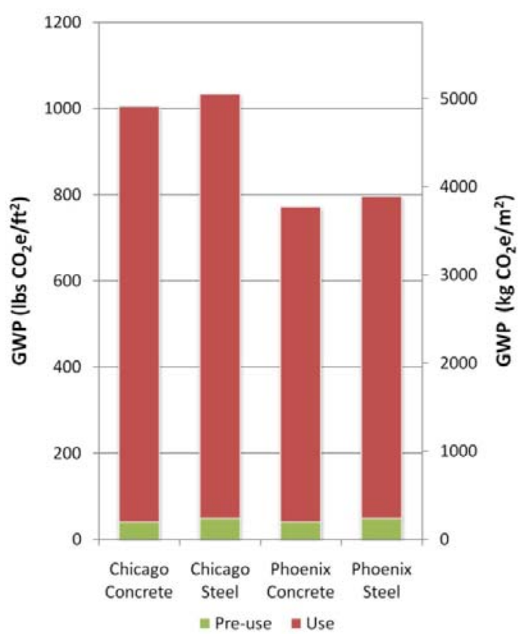

Figure 1. Total Global Warming Potential (GWP) over 60-year lifespan for commercial buildings.

Research at Lawrence Berkeley National Laboratory has shown that temperatures in urban areas rise by as much as 1-3 °C (2-5 °F), primarily because of dark-colored roofing and pavements. This is known as the urban heat island effect which results in higher cooling costs in summer. One way to reduce the heat island effect is to use light-colored, high-mass building materials such as concrete for roofing, cladding and pavements, along with strategic landscaping (LBNL 2013).

Aesthetics. A structural engineer, working closely with an architect can help select concrete with color, shape and texture for nearly any application. This marriage of structure and architecture distinguishes concrete from most other material in the sense that the surface of concrete structural systems can be exposed on the interior or exterior of a building. This helps to reduce the need for additional finish material, thus reducing environmental impact.

Concrete Mixtures. The proportions of ingredients used for concrete mixtures can have a significant influence on the environmental footprint of concrete, but this determination should not be limited to the mixture composition – the impacts to constructability and performance of the structure must also be considered. For example, the mix design shown in Table 1 has 50% SCMs, which would generally be considered to have a reduced carbon footprint. Is this mixture sustainable? It’s difficult to tell. This mixture may have higher compressive strength than that required for structural design. If the concrete was being proposed for a mass concrete member, one would generally need to have 70% slag cement to reduce temperature rise from heat of hydration. If this concrete mixture was being proposed for post-tensioned floors, it might not gain strength at an early enough age to allow post-tensioning in a timely manner, thus prolonging the construction schedule.

Table 1: Example concrete mix design

Portland cement	208 kg/m^3 (350 lb/yd^3)
Slag cement	178 kg/m^3 (300 lb/yd^3)
Silica fume	30 kg/m^3 (50 lb/yd^3)
Coarse aggregate	1068 kg/m^3 (1800 lb/yd^3)
Fine aggregate	712 kg/m^3 (1200 lb/yd^3)
Water	178 kg/m^3 (300 lb/yd^3)
Air content	6%

In general, for a concrete mixture to be sustainable, it must be able to meet the performance requirements of the owner, designers, contractor and producer in addition to meeting the following criteria that support sustainable construction:

- Minimize Energy and CO_2 Footprint
- Minimize Potable Water Use

- Minimize Waste
- Increase Use of Recycled Content

INFLUENCE OF PROJECT SPECIFICATIONS

Specifications for concrete construction establish project requirements that the contractor and material suppliers must comply with. Project specifications that adhere to industry standards are generally supportive of performance-based criteria and sustainable concrete construction. However, many project specifications incorporate additional, unnecessary prescriptive requirements that tend to detract from concrete construction retaining its environmental benefits.

A prescriptive specification imposes constraints on concrete mixture proportions or means and methods of construction. Examples of prescriptive criteria include limits on the composition of the concrete mixture such as minimum cement content, limits on the quantity of materials, maximum water-cementitious materials (w/cm) ratio, grading of aggregates, etc.

A performance specification outlines the characteristics of the hardened concrete, depending on the application and aspects of the construction process that are necessary. These requirements should not restrict innovations by the concrete producer or the concrete contractor, with the approval of the licensed design professional. Performance specifications should clearly specify the test methods and the acceptance criteria that will be used to verify and enforce the performance criteria. Performance specifications should provide the necessary flexibility to the contractor and producer to provide concrete mixtures that meet the performance criteria. The general concept of how a performance-based specification works is as follows:

- There would be a qualification and certification system that establishes the standards for concrete production facilities and the people involved.
- The design professional would define the performance requirements of the concrete for the different members in the structure.
- Producers and contractors would partner to ensure that the right mixture is designed, delivered and installed to meet the performance criteria.
- The submittal would document that the mixture will meet the specification requirements and include 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.
- There would be a clear set of instructions outlining what happens when concrete does not conform to the performance criteria.

Common prescriptive requirements found in concrete specifications and their effects on performance, including sustainability, are summarized in Table 2. Most of these requirements do not support sustainability goals and often increase the cost of concrete.

Table 2. Impact of Prescriptive Specification Provisions

Specification Provision	Impact		
	Sustain-ability	Perform-ance	Cost
1. Restrictions on Type and source of cement	↓	↕	↑
2. Restricting the use of cements conforming to ASTM C1157 and ASTM C595	↓	↔	↔
3. Restriction on cement alkali content	↓	↔	↑
4. Restriction on type and source of aggregates	↓	↔	↑
5. Restrictions on characteristics of aggregates	↓	↔	↑
6. Invoking a minimum content for cementitious materials	↓	↕	↑
7. Prescriptive requirements toward green building credits	↑	↕	↕
8. Restriction on quantity of SCM	↓	↓	↑
9. Restriction on type and characteristics of SCM	↓	↓	↑
10. Restriction on type or brands of admixtures	↔	↓	↑
11. Establishing same class of concrete for all members	↓	↔	↑
12. Requiring higher strength than required for design	↓	↔	↑
13. Invoking maximum w/cm when not applicable	↓	↔	↑
14. Requiring a high air content	↓	↓	↑
15. Restricting the use of a test record for submittals	↓	↓	↑
16. Restriction on changing proportions when needed to accommodate material variations and ambient conditions	↓	↓	↑
17. Requirement to use potable water	↓	↕	↑
18. Use of recycled aggregates and materials for specific applications	↑	↕	↓
19. Ensuring reliable testing	↑	↔	↓
20. Accurate estimation and optimized scheduling of concrete delivery	↑	↔	↓
21. Specific limitations on slump	↓	↓	↕

The intended concrete performance can be attained without having to meet these prescriptive requirements. The following is a detailed discussion of how prescriptive criteria listed in Table 2 can influence performance and sustainability of concrete (Bickley 2006, Lobo 2010, Obla 2010, Obla 2007, ACI ITG-8R-10 2010, Hover 2008, NRMCA P2P Initiative 2013).

1. **Cement Type and source:** Specifications often restrict Type (e.g. ASTM Type II) of cement or restrict use to certain sources. Unless there is a Code requirement or specific reason for durability or other property, these restrictions should be avoided. These restrictions may force the use of materials unfamiliar to the producer, require a greater over-design, cause incompatibility with other materials and require material to be transported a longer distance. These restrictions do not support environmental goals and most often increase the cost of concrete.
2. **Cement specification:** Specifications often restrict the use of cements to ASTM C150. Blended cements conforming to ASTM C595 and performance cements conforming to ASTM C1157 are optimized for performance by cement manufacturers and often have a lower carbon footprint per unit of product. Permitting the use of blended cements support sustainability. Cost implications are neutral. Concrete producers still have the flexibility of using additional SCMs to develop mixtures to meet the needs of a project.
3. **Low alkali cement:** Specifications often require the use of a low alkali cement to minimize the occurrence of deleterious expansive cracking due to alkali silica reactions. Manufacturing low alkali cements increases the use of natural resources and energy and can increase waste generation during manufacture. Mitigation of alkali silica reactions with locally available potentially reactive aggregates can be accomplished using SCMs and admixtures. Requiring the use of low alkali cement will increase cost and not support environmental goals.
4. **Type and source of aggregate:** Specifications may restrict the aggregate type and require the use of a specific source – crushed vs. gravel, mineralogy, specific supplier or source, etc. This could force the use of materials that the producer may not be familiar with and prevent mixtures from being optimized for performance. The cost of aggregate might increase due to transportation. These requirements will not support sustainable development and can adversely impact performance.
5. **Characteristics of aggregates:** Specifications often place restrictions on the characteristics of aggregates, such as grading, specific gravity, particle shape and size. In some areas, local aggregate supplies may not comply with all requirements of referenced specifications, such as ASTM C33, but have a good history of use. However, when the requirements prevent the use of local materials or require use of materials that are not commonly used or locally available, it will increase cost and detract from sustainable development without significant benefits in concrete performance.
6. **Minimum cement content:** Many specifications impose minimum cement content for different classes of concrete. Requiring minimum cement content constrains the innovation of the concrete producer to optimize concrete mixtures, can result in inherent incompatibility with other requirements of the specifications, such as strength or w/cm. These can result in unintended

consequences, such as increased volume change due to temperature or drying shrinkage that will result in cracking. Limits on minimum quantity of cement impact cost and meeting environmental goals with questionable benefits to quality, performance and durability.

7. **Prescriptions on concrete mixtures for "green building" credits:** Increasingly, projects seeking green construction credits impose prescriptive requirements on concrete mixtures, such as a minimum replacement for cement or minimum recycled content. These requirements can often impact the performance of fresh and hardened concrete properties, such as setting characteristics, ability to place and finish and rate of development of in-place properties. In the long run this may impact the quality of construction or the service life of the structure. The implication to initial cost may be reduced but it could cost more in the long term. The benefit to sustainable development is questionable if the performance requirements for the structure are not achieved or its service life is reduced.
8. **Quantity of SCM:** Some specifications place limits on the quantity of SCMs. Often the use of more than one type of SCM is prohibited. This prevents optimizing concrete mixtures for performance and durability. The only Code restriction here is for exterior concrete subject to application of deicing chemicals. Maximum limits on the quantity of SCM increases cost and does not support sustainable development.
9. **Type and characteristics of SCMs:** Specifications often prohibit the use of some types of SCMs or impose restrictions over and above those in the material specifications – such as on lime content, alkali content, loss on ignition or grade of slag cement. These will prevent the use of locally available materials that likely have good past performance and will require materials to be imported. The result will increase cost, detract from meeting environmental goals, while the impact on performance is questionable.
10. **Type and brand of admixtures:** Most specifications include a list of specific admixture brands and suppliers. Often the listed products are no longer available in the market. Concrete producers often have business relationships with admixture suppliers and have experience with use of certain products. Forcing the use of different products will impact the ability of the concrete producer to provide concrete mixtures of consistent quality and performance.
11. **Same class of concrete for all members:** Concrete members in a structure are often designed based on different strength levels and exposure classes. Requirements for foundations may differ from beams and columns; slabs may have different requirements. Specifications often indicate the same class for all concrete on a project. This can cause problems during placing and finishing. There are considerable cost savings and environmental benefits if the concrete is specified as required for the different structural members on a project.
12. **Higher strength than required by design:** If a higher strength is specified or required for durability, the designer should use that to advantage when designing the structure and minimize section size when applicable.
13. **Max w/cm when not required:** The Code requires the use of a maximum w/cm for durability and assigns a minimum specified strength that is in alignment with the required w/cm. Many specifications incorporate limits on w/cm for elements

not subject to durability concerns. This includes all interior concrete. Imposing a low w/cm limit likely increases the cement content of concrete mixtures and affects the ability to place and finish concrete. Use of a max w/cm, where not required, increases cost and does not support sustainable development.

14. **Air content:** Air content requirements for concrete vary by aggregate size because the volume of paste changes. It is further permitted to reduce the specified air content when the specified strength exceeds 35 MPa (5000 psi). In many vertical members that will not be critically saturated and require a high design strength, air-entrained concrete may not be required. Air-entrained concrete is not required for interior structural members. Most specifications state a constant air content requirement regardless of aggregate size and often increase it, assuming this will improve freeze-thaw durability. Air content reduces strength and additional cement is required to offset this strength decrease. This can result in increased propensity for thermal and shrinkage cracking. Specifying air content that is not appropriate for a structural member increases cost and materials, while likely reducing performance and sustainability.
15. **Use of test record for submittals:** Specifications often indicate that the concrete mixture should be designed to produce an average strength at a fixed value greater than the specified strength. This essentially prohibits the use of past test records that allows for a statistically based average strength. This discourages concrete producers that have good quality control from optimizing concrete mixtures to a lower strength level and thereby conserving materials. This requirement increases cost, does not support sustainable concrete and could result in unintended problems due to high cementitious materials content.
16. **Restriction on changes to mixtures:** Ingredient materials vary as do environmental conditions during the project. Real time adjustments are necessary to accommodate these variations and to ensure consistent concrete characteristics. Several specifications prohibit such minor changes to concrete unless a submittal, often with supporting test data, is provided to the engineer of record. It is recognized that the engineer of record should be notified for major revisions to mixtures, but prohibition of changes can cause considerable negative impact to concrete performance.
17. **Use of potable water:** ASTM C1602 addresses the quality of water that can be used to produce concrete and includes provisions to permit the use of non-potable water with proper testing and evaluation. Specifications that prohibit the use of non-potable water increase cost and result in the generation of considerable volumes of waste water. Specifications that require the use of potable water detract from the development and use of sound environmental management practices at concrete production facilities.
18. **Recycled materials and aggregates:** There are applications for concrete that can accommodate the use of recycled aggregates or other materials with minimal impact to concrete quality. Crushed returned concrete can be used as a portion of the aggregate in concrete for some applications to conserve virgin materials and minimize waste. The use of recycled material can contribute to credits in green construction rating systems. The use of crushed concrete as aggregate is recognized in industry standards. Judicious use of these materials will reduce cost,

conserve natural resources and landfill space with minimal impact on performance.

19. **Reliable testing:** While this may not seem pertinent, improper testing procedures will increase variability and result in greater over-design of concrete mixtures. When concrete producers are aware of improper testing, they protect themselves by increasing the cementitious materials in concrete mixtures. This results in increased cost and does not support sustainable development. Selection of testing agencies should be based on quality of work, conformance to ASTM C1077 and having certified personnel conducting tests. Test reports should be distributed to producers as soon as available to help identify potential problems early.
20. **Scheduling and estimating:** Concrete should be scheduled properly and a good estimate of the required volumes should be communicated to the plant during and toward the end of a pour. Delays on the jobsite will result in rejected loads through no fault of the concrete producer. Ordering excess concrete increases waste that is expensive to manage. Ordering small loads will increase cost and likely result in concrete that is more variable than that delivered in full size loads. Allowing the contractor to have input on construction joint location can help reduce this problem.
21. **Specific limitations on slump:** Slump should be selected by the contractor and concrete supplier based on the placement and finishing requirements of the concrete. With the use of water reducing admixtures slump cannot be taken as a representation of the quantity of water in the mixture. The target slump can be provided to the engineer of record in the submittal and can be used as a basis for quality assurance. Placing limits on slump usually results in reduced sustainability and performance and can increase cost.

SUGGESTED SPECIFICATION

The National Ready Mixed Concrete Association (NRMCA) has developed a guide specification to help designers improve concrete specifications (NRMCA Publication 2PE003 2009). The following are a few general recommendations for proposed specification language (*italics*):

Manufacturer Qualifications: *Concrete shall be supplied from concrete plants with the following current certifications:*

- *NRMCA Certified Concrete Production Facility*
- *NRMCA Green-Star Certification*
- *NRMCA Sustainable Concrete Plant Certification, Bronze level or higher.*
- *Quality Control personnel with responsibility for concrete mixtures certified as an NRMCA Concrete Technologist Level 3*

NRMCA has developed several certification programs to help qualify concrete producers to design, batch and deliver concrete for performance-based products while meeting the strictest environmental requirements (NRMCA Certifications 2013).

Concrete Mixtures: *Prepare design mixtures for each class of concrete on the basis of laboratory trial mixtures or field test data, or both according to ACI 301. Design mixtures shall meet the specified strength requirements listed below:*

Application	***Nominal Max. Aggregate Size****	***Exposure Class****	***f'c****
Interior slabs and beams	*19 mm (3/4 in.)*	*F0, S0, P0, C0*	*28 MPa (4,000 psi)*
Interior Columns	*19 mm (3/4 in).*	*F0, S0, P0, C0*	*35 MPa (5,000 psi)*
Footings	*38 mm (1-1/2 in.)*	*F0, S1, P0, C1*	*28 MPa (4,000 psi)*
Exterior slabs and beams	*19 mm (3/4 in.)*	*F3, S0, P0, C1*	*35 MPa (5,000 psi)*

*Values are for example only. Each project would require a different set of criteria.

This is where the structure engineer can specify physical characteristics and mechanical properties of the concrete along with the durability criteria without prescribing the mix design. NRMCA's guide specification provides alternate performance tests and criteria for ASR, shrinkage etc.

Product Qualifications: *Concrete producer shall submit Environmental Product Declaration(s) meeting the requirements of ISO 14025 for Type III EPDs for each mix proposed for the project.*

Environmental Product Declarations (EPDs) are reports produced by a product manufacturer that provide quality assured and comparable information regarding environmental performance of its product. New standards such as LEED v4, Architecture 2030 Challenge for Products will require EPDs for products to demonstrate superior environmental performance (NRMCA Sustainability 2013).

CONCLUSION

An environmentally conscious building owner is interested in a concrete structure that provides a long service life without significant defects and has a low environmental footprint, not necessarily how much cement it contains. Using a performance specification, the concrete producer is free to select the mixture proportions and is held responsible for meeting the performance criteria. Since performance specifications would allow for mixture optimization and mixture adjustments during the project, there is an incentive for the producer to invest in improved quality, technology and lab facilities. With a performance specification, a quality concrete producer can improve product quality, stimulate innovation, reduce construction cost and minimize construction time – while reducing environmental footprint.

REFERENCES

ACI 318-11. (2011). *Building Code Requirements for Structural Concrete and Commentary*. American Concrete Institute, Farmington Hills, MI.

Ochsendorf, J., et al. (2011) *Methods, Impacts, and Opportunities in the Concrete Building Life Cycle.* Massachusetts Institute of Technology Concrete Sustainability Hub, Cambridge, MA.

Lawrence Berkeley National Laboratory (LBNL) Urban Heat Island Group, http://heatisland.lbl.gov/learn. (2013). Accessed January 2013.

Bickley, J., Hooton R. D., and Hover K. C. (2006). *Preparation of a Performance-based Specification for Cast-In-Place Concrete*. RMC Research and Education Foundation, Silver Spring, MD.

Lobo, C.L. (2010). “Impact of Project Specifications on Sustainable Development.” Concrete InFocus, V. 9, No. 5, NRMCA, Silver Spring, MD.

Obla, K. H. (2010). “Performance-Based Specifications for Concrete to Advance Sustainable Development,” SP 269, American Concrete Institute, Farmington Hills, MI, pp. 7-20.

Obla, K. H., and Lobo, C. L. (2007) “Acceptance Criteria for Durability Tests.” Concrete International, V. 29, No. 5, ACI, Farmington Hills, MI, pp. 43-48.

ACI ITG-8R-10. (2010). *Report on Performance-Based Requirements for Concrete.* ACI, Farmington Hills, MI.

Hover K. C., Bickley, J., and Hooton R. D. (2008). *Guide to Specifying Concrete Performance Phase II Report of Preparation of a Performance-based Specification for Cast-In-Place Concrete*. RMC Research and Education Foundation, Silver Spring, MD.

NRMCA P2P Initiative, http://www.nrmca.org/p2p. (2011) NRMCA, Silver Spring, MD.

NRMCA 2PE003. (2009). *Guide to Improving Specifications for Ready Mixed Concrete*, NRMCA, Silver Spring, MD.

NRMCA Certifications, http://www.nrmca.org/certifications. (2013). NRMCA, Silver Spring, MD. Accessed January 2013.

NRMCA EPD Program, http://www.nrmca.org/sustainability/EPDProgram. (2013). NRMCA, Silver Spring, MD. Accessed January 2013.