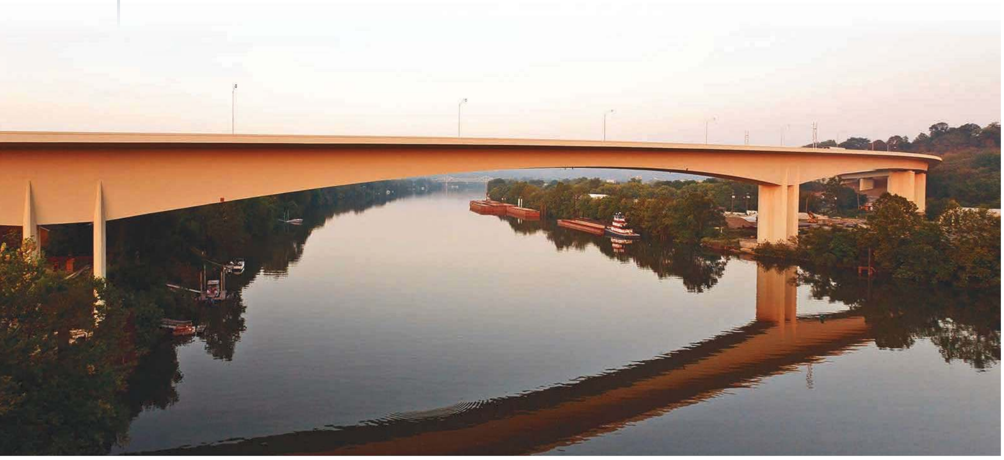
PERSPECTIVE

A Vision for Structural Concrete Research

by Benjamin A. Graybeal, Federal Highway Administration



The combination of prestressed concrete and segmental construction allowed a main span length of 760 ft for the Kanawha River Bridge, W.Va. Photo: T.Y. Lin International.

From the advent of portland cement concrete in the early 1800s, to the construction of the first reinforced concrete bridges in the United States in the late 1800s, to today's widespread use of concrete throughout the physical infrastructure, the technology of concrete has been continually advancing. These two centuries of progress have brought about structure types, construction methods, and material properties that could scarcely have been imagined when Aspdin, Vicat, and others were rediscovering the long-forgotten Roman secrets of castable stone. These advancements have largely resulted from systematic investigations that build on past knowledge to expand future applications. Research, whether geared toward addressing an immediate challenge or grasping a potential opportunity, has been the key methodology employed in the steady advancement of concrete technology.

Looking back over the past few decades reveals many game-changing advancements that have enabled our sector's current successes. Prestressing allows for dramatic increases in structural efficiency by shifting the stress state in the concrete toward its strength in compression. Admixtures, most notably high-range water reducers, allow for modification and enhancement of fresh and hardened properties, thus enabling the tailoring of concrete to specific applications. Reinforcements with enhanced strength and durability properties have allowed for the construction of robust, efficient structures. These sorts of advancements emanate from perceptive recognition of challenges and opportunities.

Supplemental cementitious materials enhance the performance properties of concrete. From left to right, Class C fly ash, metakaolin, silica fume, Class F fly ash, slag cement, and calcined shale. Photo: Portland Cement Association.

Challenges

Today, the challenges faced by our infrastructure demand innovative solutions and continual advancement. The clearest path to success is through systematic research that address today's pressing needs while also striving toward transformational innovations that can continue structural concrete's role as the cornerstone of our structural systems. The concrete bridge community needs to balance its research priorities to ensure that near-term challenges are addressed while also striving for broad-based advancements in our foundational technology.

All too often in recent years, research funding organizations have been unwilling or unable to leverage their funds to create a strategic vision for the future of structural concrete. Instead, research dollars have been disproportionately directed toward bandage solutions that, at best, provide short-term relief to an applied engineering concern. These types of research are necessary, but through collaboration, coordination, and a willingness to strategically engage promising solutions, our researchers can also deliver the transformative innovations that will change the way concrete is used in the future.

This method of strategically directing applied engineering research toward pressing challenges is not new. One recent example is the push toward accelerated bridge construction. Accelerated bridge construction stems from the need to reconstruct degraded infrastructure with minimal impact to users. The build-out of our roadway infrastructure was primarily green-field construction, while the current reconstruction phase is space- and time-constrained in ways that can preclude traditional construction techniques. Dozens of innovative solutions have been developed to address this situation, many revolving around prefabrication and heavy-lift technologies that allow for increasingly larger portions of the infrastructure to be constructed off-site and outside the critical path. Collaboratively, the bridge community has funded and executed the needed research.

The systemic challenges facing the use of concrete in infrastructure

The concept of accelerated bridge construction is changing the way that bridges are replaced, such as the Massena Bridge in Iowa. Photo: Iowa Department of Transportation.

are quite familiar. In an ideal world, concrete would express enhanced mechanical properties allowing for greater structural efficiencies and more cost-effective structures. Concrete would be dimensionally stable during the hydration reaction, allowing for a reduced likelihood of cracking. Concrete would be less permeable and more resistant to cracking, thus increasing the durability of the composite. Concrete would be more sustainable. And innovations, regardless of the type, would be sufficiently robust to stand up to the rigorous demands placed on conventional solutions.

The way to address these concerns and achieve our goals is to strategically invest in the conduct of research that addresses tomorrow's needs today. Yes, funding is always constrained and research carries inherent risk, but the risks of not effectively engaging the research community to help address these challenges is even greater. A lack of focus on strategic challenges will result in a status quo mentality and eventually an atrophic community that is only able to look to past solutions for guidance in addressing present challenges.

Strategic Opportunities

From my vantage point, I see four key topic areas that are ripe for advancement through strategic investment of research capital. The first is *crack mitigation in structural concrete systems*. Advancements in concrete matrix design that reduce permeability are for naught if the concrete is overly susceptible to cracking. Concrete can be designed to have greater tensile strength, less shrinkage, and narrower cracks. Advancements in this topic area will allow for structures whose durability in aggressive environments, such as bridge decks, can exceed today's service life estimates.

The next is *alternative concrete matrices*. Over the past few decades, researchers investigating the fundamental performance of concrete and similar heterogeneous binder-based systems have developed concrete-like materials that use different chemical reactions to glue together the matrix. Some of these alternative concretes offer similar mechanical performance to conventional concrete but with the added benefit of being tailorable to specific construction situations while also being more sustainable. Innovation in this area will significantly broaden the applicability of concrete to include a much larger toolbox of mixture proportions adapted to suit a wide range of applications.

The third relates to the performance of concrete structure under *combined loadings*. Traditionally, concrete research has tended to investigate performance attributes through isolation of variables. Although this method does provide for reasonable first-order assessments of performance, it does not address the synergistic effects that occur at the structural system level when time, mechanical response, and durability response become intertwined. Topics such as the service and ultimate performance of concrete bridge decks subjected to decades of truck loading and intermittent deicing salt application are of immediate interest.

The fourth pertains to the emerging classes of concrete with *enhanced material properties*. Concretes are available today that can exhibit more than 20 ksi of compressive strength, more than 1 ksi of tensile strength, sustained post-cracking tensile capacity, and diffusion coefficients more than an order of magnitude less than today's conventional concrete. One-for-one replacement of conventional concrete with these emerging concretes may not be economically appropriate due to the higher material costs and the lack of structural benefits. In short, there is a need for research to assess the most appropriate applications of these concretes, to develop the necessary design specifications, and to work with owners to implement this emerging class of concrete.

The Future

Strategic investments aimed at addressing our biggest challenges will pay dividends in the future. As a community, we have the opportunity to align our resources with our needs. Visionary research can propel us through another century of concrete innovation.

Structurally optimized, ultra-high-performance concrete, pi-girder superstructure bridge in Buchanan County, Iowa. Photo: Benjamin Graybeal, Federal Highway Administration.