PERSPECTIVE

# SUSTAINABILITY

## For the Concrete Bridge Engineering Community

by Dr. Tess Ahlborn

Concrete is the number one building material in the world and ranks second only to water as the most consumed substance of our time. As bridge engineers, we use concrete in every bridge project from foundations and piers to abutments, superstructures, bridge decks, and barriers. Our cultural and professional responsibility has been to design safe, economical, and constructible systems that meet the current and relatively short-term future needs of the owner and the public. While we must continue to accomplish these goals, we must also consider the impact of our choices on future generations.

Almost everyone has heard about sustainability, usually in an environmental context. As the awareness of sustainability grows, we should question whether concrete bridges can really make an impact on the sustainability movement. The intuitive answer is "absolutely; concrete structures can and do have a positive impact." This issue of *ASPIRE*™ and the next three issues focus on concepts of sustainability as they relate to concrete bridge systems.

### Concepts of Sustainability

Sustainability has received vast awareness recently, specifically related to the impact that humans have on the earth's resources and environment. This attention is being focused on every aspect of our built environment; the homes we live in, the buildings we work in, the cars we drive, and the roads we drive on. Is sustainability just the next buzzword or fad? Considering how many aspects of our lives are affected, most authorities believe sustainability will become a driving force that permeates all facets of our lives.

The Daggett Road Bridge environmental constraints played a key role in determining the type of bridge. Photo: DMJM Harris.

The Fifth Street Pedestrian Plaza Bridge in Atlanta provided a pedestrian-friendly environment. Photo: ARCADIS U.S. Inc.

A sustainable design involves consideration of its impact on society, environment, and economy. A balance must exist between these three elements to provide the best solution. Sustainable designs reduce the amount of waste material, minimize the social impact of construction congestion, and cost less per year of service over the life cycle of the structure. The choices that we make not only affect the construction costs or environmental impact of a project, but clearly affect the public perception of our engineering solutions. Assessing the carbon footprint of an individual, process, industry, or country is one way to assess and quantify sustainability. However, this tends to focus only on one aspect—the environment—while diminishing the social and economic tenants of sustainability. Now, more than ever, we need innovative solutions that respond to our economic and social well-being.

**"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."**

The commonly accepted definition of sustainability, as used by the United Nation's World Commission on Environment and Development in their 1987 report titled Our Common Future, states "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." To the concrete bridge community, this definition means designing, constructing, and maintaining context-sensitive bridges with long-term durability, low life-cycle impacts, sensitivity in the selection of materials and methods, and a minimal impact on the environment throughout the bridge's life.

### Moving Forward from Common Practice

The bridge engineering community has been practicing many sustainable concepts for decades. Rapid construction, contractor alternate designs, value engineering, lean manufacturing, and extending service life through reliable and durable systems all contribute to sustainable practices. Rapid construction concepts incorporate a get in, get out, and stay out philosophy, while demonstrating improved quality through rigorous quality control and assurance. These concepts limit the adverse affects of detours and traffic congestion on commuters and local businesses. Contractor alternate designs


## *Life Cycle of Concrete Bridges*

The life cycle of a bridge plays an important role in determining the sustainability of the system. Life cycles can be evaluated in terms of environmental or economic impacts. Assessing the life cycle can help us become more aware of sustainable solutions for bridges. Life-cycle models, whether through assessments, inventories, or cost analysis, are complex and rely on consistent and available historical information.

Life-cycle assessment (LCA) is an environmental analysis and considers the many stages of a bridge's life. An LCA for a concrete bridge would include such items as the extraction of natural resources to produce the cement and aggregate, the manufacturing process (whether cast-in-place or precast), and the decommissioning or reuse of the structure. LCA also assesses the environmental impact of the construction techniques used initially in addition to the maintenance, repair, and rehabilitation segments of a bridge's life. A comprehensive summary of the environmental impact of a bridge can be gained through LCA.

Life-cycle inventory (LCI) is the primary component and the first step of LCA. It accounts for the environmental impact of each component of a bridge independently. For example, LCI data on cement and concrete production, such as that published by the Portland Cement Association (http://www.cement.org), is separate from the data related to bridge inspection. Inspection data leads to a better understanding of overall bridge durability and a maintenance schedule. Detailed information is gathered for the raw materials and the embodied energy necessary for each segment. Because the largest component of embodied energy of a concrete bridge comes from the production of cement, reducing cement content or replacing it with supplementary cementitious materials can often considerably lower the embodied energy of the entire system.

Life-cycle cost assessment (LCCA) is common for the purchase of many fixed assets and allows for a more holistic evaluation of costing rather than basing decisions solely on the initial costs. A discounted cash-flow analysis using estimates of costs throughout the various life stages of a bridge is used to convert costs to an equivalent uniform cost for comparison purposes.

Bridge inspection, implemented only about 30 years ago, is a necessary requirement for today's aging infrastructure (see "Safety and Serviceability on page 47). Preventive maintenance can significantly improve the life of a bridge. We must insist that preventative maintenance budgets be an integral part of a bridge's life and not be reduced or eliminated under budget constraints. Historical information is somewhat unreliable through searchable databases, as many states overwrote data with updated inspection information keeping previous records only in paper copy. But we cannot allow the need for digital historical data to impede the progress and implementation of new technologies. As bridge management systems are refined and cost data is collected, life-cycle costs will become less subjective.

and value engineering allow the owner to consider alternatives and reduce initial costs or long-term maintenance and repair. Efficiency in the plant or on-site contributes to optimized manufacturing of concrete systems and better use of resources.

Extending the service life of a structure, through better materials and adaptable designs translates to less time and energy spent on maintenance and future reconstruction. Through the precepts of the Highways for LIFE Program (www.fhwa.dot.gov/hfl), a structure that meets both the needs of today and those of the future will not require premature replacement. For example, the removal from service of a bridge that no longer meets the functional needs of the user should be avoided when the structural integrity does not warrant replacement.

The Mill Street Bridge in Epping, New Hampshire, was built in only 8 days to minimize construction-related traffic delays and improve work zone safety.

## Sustainable Bridge Solutions

There are many design concepts that can assist designers in creating the most sustainable bridge solutions including teamwork, rating systems, and innovation.

The concept of teamwork centers around the idea that all parties must coordinate efforts for bridge projects so that sustainable goals can be met for every new and rehabilitated bridge. One example is the Green Highway Partnership (www.greenhighways.org). This is an overarching initiative for creating and promoting sustainable transportation infrastructure through partnerships between organizations and industry.

While there are no established sustainability rating systems for bridges, many of the sustainable construction practices encouraged in the building rating systems are applicable. Whereas the building rating systems consider occupant comfort and energy conservation, bridges need to consider the effect that construction and maintenance will have on the users of the bridge. Life-cycle costing can show that long-term cost savings on bridges are realized through the use of durable, long-lasting materials.

The building sector, through the U.S. Green Building Council, has developed and published a highly recognized rating system to assist key stakeholders in understanding and assessing the environmental impact of choices made regarding building systems. While the Leadership in Energy and Environmental Design (LEED) rating system does not directly apply to the transportation infrastructure, the concrete bridge sector can easily borrow many concepts to show how sustainability and concrete technology merge to provide systems with fewer impacts.

Such considerations include the following:

- Concrete bridge decks have a higher solar reflectance than other bridge deck materials, reducing the heat island effect in urban areas;
- Construction waste management can be improved for better utilization of materials and resources;
- Paints, stains, and sealers range in volatile organic compound emissions and should be considered along with the durability of such components;
- Simple solutions incorporating alternative transportation modes, such as bicycling and walking, should always be considered;
- Site work solutions, such as planting native landscaping, may reduce run-off and result in more efficient drainage systems;
- Rapid construction and prefabrication drastically reduce congestion, hours and fuel spent in delays, and hours spent working in hazardous construction zones; and
- Concrete, whether cast-in-place or precast, is produced locally, using local workers without the cost and effects of lengthy hauling distances.

Materials and resources should be considered for all stages of a concrete bridge's life, from using regional materials to increasing the recycled content of concrete without compromising durability. Although portland cement manufacturing produces only 1.5 to 2.0 percent of $CO_2$ emissions in the United States, the use of supplementary cementitious materials, such as fly ash, ground-granulated blast-furnace slag, and silica fume can have an impact on reducing the quantity of portland cement used while finding positive beneficial ways to utilize industrial by-products and produce better performing concrete. In general, the use of these materials improves the long-term durability of concrete.

Undoubtedly, the most important element from the LEED rating system that applies to concrete bridges is the encouragement of innovation. New developments in concrete materials technology, durable structural details, improved maintenance, and low life-cycle costs, can all lead to more sustainable systems.

## A Place for New Technologies

Moving the industry forward in sustainable fashion, through engineering, production, and construction, while recognizing the importance of inspection and maintenance or repair, will require the implementation of new technologies. Innovation can be adopted in many aspects of a concrete bridge, through many stages of its life. Some aspects include cement and aggregate type, concrete mix proportioning, and new reinforcing materials.

Consider the use of innovative materials such as ultra-high performance concrete (UHPC). This material provides a new approach to long-term durability with compressive strengths from 25,000 to 30,000 psi and a corresponding high tensile capacity. UHPC has a high cement content, nearly 1200 pcy—twice the amount used in a concrete mix for most bridge decks. While first impressions may exclude the use of UHPC solely based on cement content, significantly more efficient structural design may require only one quarter of the material. Or, the material may lend itself to new hybrid solutions. Combine that with UHPC's long-term durability and the bridge life may easily exceed a few hundred years with little preventative maintenance required.

Reinforcing steels used in concrete bridges will also be affected by new technologies. While reinforcing steels are made from nearly 100 percent recycled material, changes to material content or coatings, and the use of high performance concretes can improve the durability through enhanced corrosion resistance and protection. Reinforcing materials with higher strengths are being investigated for incorporation into the AASHTO's LRFD Bridge Specifications under research sponsored by the National Cooperative Highway Research Program (www.trb.org/CRP/NCHRP/NCHRPProjects.asp).

Lightweight aggregates, particularly those engineered from natural resources can improve the sustainability of concrete. Lightweight aggregates and lightweight concrete require less fuel to transport. Other engineered lightweight aggregates, including by-products of other manufacturing processes, may provide sustainable solutions if performance can be documented. In addition, we must understand the energy consumption and environmental impact of producing such aggregates relative to aggregates in use today.

## The Role of Engineering Education

Educating the bridge engineering community about sustainable solutions is needed at all levels, from the new graduate to the seasoned engineer. As an engineering professor, I am often asked "how does one engineer sustainability?" Students today are being introduced to sustainable concepts through general education. In fact, the Accreditation Board for Engineering and Technology (ABET) criteria provides a framework for including sustainability in undergraduate programs. Economics and ethics are a necessary foundation for understanding the impact of innovative technologies on our society. Graduate programs are expanding to include sustainability certificates; thereby, encouraging students to embrace social and economic aspects in parallel to their engineering studies.

**Educating the bridge engineering community about sustainable solutions is needed at all levels.**

Continuing education for practicing engineers can be acquired through conferences that sponsor sustainability sessions covering the basic principles, case studies, and panel discussions nationally and internationally. Magazines like *ASPIRE*, which reach the entire spectrum of public and private stakeholders in the bridge community, can provide education on timely topics related to sustainability. While the bridge engineering community is well on its way, we will need to improve our ability to apply life-cycle costs, understand life-cycle inventories, and integrate life-cycle assessment into our projects.

Research, a key component in today's engineering community, can lead to better understanding of sustainable solutions. Even ideas for reuse of concrete bridges once they reach their service life should be considered. Research funding is often limited, but intrigue and necessity will continue to move our technologies forward.

## Closing Remarks

Engineers and engineering design practices will have a significant impact on a sustainable future. We have the ability to set policy towards sustainable solutions for the transportation infrastructure, refine our nation's best practices, and implement new technologies. The initiatives that the concrete bridge engineering community are undertaking, including the sustainability efforts of the sponsors of *ASPIRE* and agencies such as the FHWA, AASHTO, and NCHRP, will lead to more sustainable bridges and a more sustainable future.

Whether you are a state or federal employee, county engineer or commissioner, design consultant, contractor, supplier, academic, or a member of the many organizations affiliated with concrete bridges in the private, rail, or highway system, sustainability must take a front seat. A balance must exist between the social, economical, and ecological benefits of a bridge design. Topics linking sustainable development and concrete bridge technology in upcoming *ASPIRE* articles will contribute to your awareness of these important issues and be your driving force for sustainable concrete bridges.

A truly sustainable concrete bridge will meet context-sensitive concerns for the society it serves, optimize materials used, reduce environmental impacts through innovative technologies and efficient systems, improve durability to withstand the environments of the future, and have lower life-cycle costs than other structural systems. Most importantly, the concrete bridge industry's grand challenge is to merge our current culture with one that considers sustainability, recognizing that we are only beginning to plot our direction to the future.