SUSTAINABILITY of Concrete Bridges

by M. Myint Lwin, Federal Highway Administration

During the past 2 years, *ASPIRE*™ has accepted the challenge to explore and illustrate the sustainability of concrete bridges. This theme will continue throughout 2010. Many of my previous articles have also addressed this theme. In this issue, I would like to address some basic questions about sustainability.

The I-35W St. Anthony Falls Bridge used combinations of fly ash, slag, and silica fume in the different concrete mixes. Photo courtesy of FIGG, Tim Davis photographer.

Why Sustainability for Bridges?

As responsible citizens and engineers, we need to have a concern for (1) the deterioration of our environment, (2) the local and global economies, and (3) the instability in our society worldwide. Sustainability concepts will help us maintain a healthy, productive, and life-supporting environment so essential for a strong and resilient world economy.

The American Society of Civil Engineers' Code of Ethics, Canon 1 states:

> *Engineers shall hold paramount the safety, health and welfare of the public and shall strive to comply with the principles of sustainable development in the performance of their professional duties.*

It is our professional responsibility to commit to improving the environment by adhering to the principles of sustainable development so as to protect the environment and enhance the quality of life of the general public.

The Secretary of the U.S. Department of Transportation has stated that the Department of Transportation's priorities are safety, economic recovery, establishment of sustainable highway programs, and the provision of livable communities. Sustainable highway programs require investments in better roads, bridges, and tunnels; reduction of CO_2 emissions; and the utilization of carbon-absorbing materials, while avoiding negative impact to the environment. Within our communities, we need to provide safer and healthier environments, strong economies to support jobs and families, interconnected transportation modes and systems, and sustainable mobility to encourage more walking, biking, and use of public transportation.

What is Sustainability?

The classic definition of sustainability was advanced in 1987 in the report on Our Common Future by the United Nation's World Commission on Environment and Development (the Brundtland Commission):

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

This is our responsibility to future generations. Did the past generations meet the Brundtland Commission definition in providing us with opportunities to meet our needs and creativity?

There are many engineering examples that show that our ancestors created outstanding architectural structures that have lasted for thousands of years. Some examples are the Great Wall of China; the Aqueducts, Pantheon, and Coliseum of the Romans; and the pyramids of Egypt. They are inspirations to our generation to build durable and beautiful structures that will aspire future generations to create structures based on their imagination!

Is Concrete Sustainable?

The historic structures cited in the previous paragraph used cementitious materials in the form of mortars and concrete over 2000 years ago! Some of these structures are still in use today. They definitely meet the Brundtland definition of sustainable development. In short, concrete is sustainable.

At the present time, there is demand for performance-based and data-driven definitions for engineering projects and accomplishments. We need a quantifiable definition, such as:

> *Sustainability is a concept that protects or enhances our natural environment, conserves our resources, reduces intrusion on wildlife and their habitats, and avoids negative impact on the ecosystems.*

Some concrete bridges that meet these criteria include the Chillon Viaduct, Switzerland; the H3 North Halawa Valley Viaduct in Oahu, Hawaii; Blue Ridge Parkway Viaduct, N.C.; the Millau Viaduct, France; and the I-35 St. Anthony Falls Bridge, Minn.

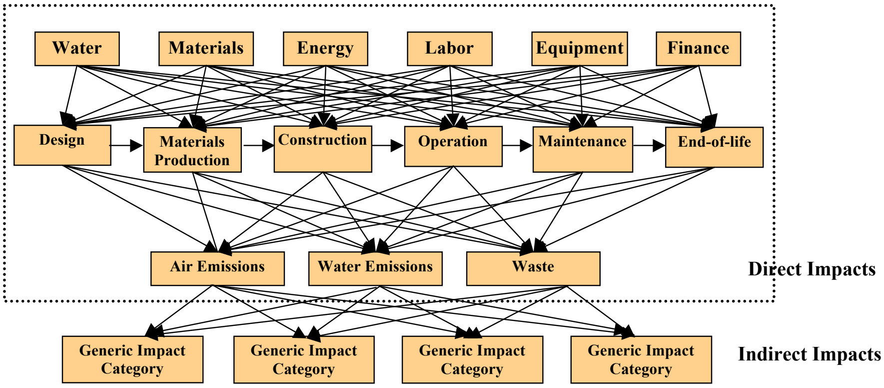


***FIGURE 1** - Total impact of bridges on the environment.*

How Do Life-Cycle Cost and Life-Cycle Assessment Differ?

Life-cycle cost (LCC) for bridges is a function of the separate costs for planning, designing, construction, operation, maintenance, and final disposal. It is an estimate of the total cost of a bridge from cradle to grave. LCC may be used for cost-benefit analysis and the cost comparison of alternate designs. On the other hand, life-cycle assessment (LCA) addresses the environmental impacts of natural resource extraction, raw materials production, product manufacturing or construction, operation, maintenance, and final disposal. The social benefits of the transportation facility must also be accounted for to provide a complete assessment of environmental, economic, and social impacts for the whole life of the structure. When all these factors are combined, bridges become very complex products for determining the total impact on the environment as illustrated in Fig. 1.

Currently there is no computer program that will help perform the complex LCA on bridges. There is a commercially available computer program, ATHENA, for performing LCA on buildings. As a simple example in using ATHENA, the following table compares the environmental impact of a reinforced concrete beam versus a steel beam of the same moment capacity as used in a building.

From the table below, the authors concluded that the production of the concrete beam required much less energy and had a lower net environmental impact than production of the steel beam.

What is Designing for Sustainability?

The design of bridges for sustainability needs to be based on a system concept involving three major components:

- Structural Design,
- Durability Design, and
- Environmental Design.

The rules for structural design are well established in documents such as the *AASHTO LRFD Bridge Design Specifications*. Durability design is less established and usually approached indirectly through the use of prescriptive specifications such as maximum water-cementitious materials ratio or maximum chloride permeability. Rarely is a direct design approach used in U.S. practice. Durability plays a very important role in LCC and LCA. Durability design deserves equal, if not more attention, than structural and environmental designs. Environmental design is a new challenge for bridge engineers. It needs to address designing and building bridges in ways that will reduce emissions, use recycled materials, conserve new materials, save energy, protect wildlife, and preserve ecosystems. Bridge engineers are challenged to be creative and innovative!

Environmental Impact	Reinforced Concrete	Structural Steel
Materials, lb	108	41
Warming Potential, lb of CO_2	22	20
Water Pollution Index	0.34	0.98
Air Pollution Index	2.01	0.46
Solid Waste, lb	4.1	4.0
Energy, kilowatt hour	39	64

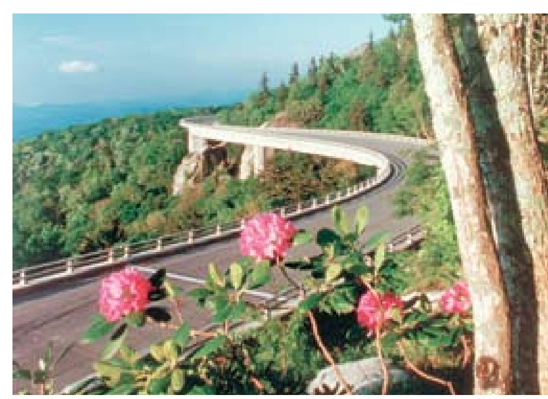
Source: Struble, L. and Godfrey, J., How Sustainable is Concrete? *International Workshop on Sustainable Development and Concrete Technology, Beijing, China, May 2004, proceedings published by Center for Transportation Research and Education, Iowa State University, Ames, Iowa, pp. 201-211.*

Closing Remarks

Let me conclude this article with thoughts by two prominent engineers on how we can achieve sustainable designs:

- "Sustainability will come from all of us in the bridge industry—owners, regulators, the public, academia, designers, and builders—working together towards a common goal." Paul Giroux, Kiewit Pacific Co.
- "A paradigm shift is necessary in United States practice to achieve the goals of extended service life and a sustainable bridge infrastructure…" Cliff Freyermuth, CLF Inc.

Since the 1987 Brandtland Commission report, sustainability has taken on wide-ranging definitions, which are applicable to innumerable situations and cases for sustaining quality of life on our good earth for generations to come.



Blue Ridge Parkway Viaduct was built from the top down and incorporated iron oxide pigments in the concrete to minimize environmental impact. Photo courtesy of FIGG.

U.S. Department of Transportation
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EDITOR'S NOTE

This article was based on a presentation by the author at the 21st Annual ASBI Convention, October 2009.