

SUPPLEMENT TO PERSPECTIVE

Sustainable Bridges

Raymond Paul Giroux, M.ASCE

The I-35W Minnesota Bridge collapse in August of 2007 was a stark reminder of the sometimes fragile state of our bridges. Bridge failures have a devastating impact, not only in the potential for loss of human life, but also the impact their failures have on our local, regional, and national economies. To be sure, bridge failures are more than just the highly visible catastrophic failures like I-35W. Bridge failures also occur when we have to reduce a bridge's load capacity, or prematurely replace a bridge.

There are about 600,000 bridges in the United States. All of these bridges play an important role in our country's transportation infrastructure. Our bridges span rivers, bays, canyons, roads, and railroads; providing critical connections and catalyst for commerce. Inexpensive transportation is essential to building and sustaining a prosperous economy and our bridges are one of the primary factors in determining what our transportation costs will be.

Bridges, as structures, take a beating. They are subject to large cyclical loadings, fatigue, extreme temperature fluctuations, rain, snow and ice, deicing chemicals, scour, accidental impacts, and so on. And because of local site conditions, each and every bridge design is unique. Accordingly, we demand more of our bridges as compared to other structures such as buildings and these demands dictate an emphasis on the functionality of a bridge's design.

Obvious functional factors that affect bridge design include criteria such as: site conditions, load capacity, span lengths, span widths, vertical clearance, seismic criteria, scour criteria, service life, maintainability, constructability, and life-cycle cost. There are of course other factors such as context sensitive factors including bridge aesthetics.

Further, creating successful designs for major bridges is an evolving process. With scientific and technical advances, engineers will explore the use of new materials and new methods of structural analysis. At the same time when society demands iconic bridges, architects will explore new shapes and forms.

Traditionally, bridge designs are culmination of a selection process that considers all of these criteria and balances the trade-offs and compromises between competing criteria. For example, society may want many of their bridges to be works of art; however, the financial burden would likely be too great for society to sustain. Likewise, a multi-span, or short-span bridge may be the least costly to build at a given site, but it may do irreparable harm to the local environment. Renovation of existing bridges in-place is often the least expensive, but may also have a huge impact on road users during construction. To be sure, there is never any shortage of debate when it comes to planning our major bridges.

History shows there has never been a shortage of debate when we select our major bridges. Historic bridges like the Brooklyn Bridge, the Golden Gate Bridge, and many other bridges were debated for years before construction began. For example, it is said the Golden Gate Bridge took thirty million dollars and thirty million words to build. More recently, modern bridges like California's new San Francisco-Oakland Bay Bridge, East Span, Buffalo's new Peace Bridge, St. Louis' new Mississippi River bridge have all proven to be controversial.

In 1983, David Billington, a professor of civil engineering at Princeton University authored the book, *The Tower and the Bridge*. He writes; "But it is in principle impossible to determine the least expensive design because cost is a social measure and not a scientific one. Cost depends not upon some laws of nature but rather upon patterns in society; it depends upon time and place."

As Billington suggests, patterns in society do evolve. Most recently we read and hear quite a lot about "sustainable solutions" as society comes to grips with the ever-increasing demand on infrastructure in the face of dwindling resources. Basically, to achieve sustainable bridges, ecological, economic, and social factors will all have to be considered in the development of our future bridge programs. Sustainable development is the challenge we face to be good stewards of society's limited natural resources, energy,

transportation, etc., not only for today's needs, but also for the needs of future generations.

In June 2008, the Brookings Institute Metropolitan Policy Program published a report titled "*A Bridge to Somewhere: Rethinking American Transportation for the 21st Century*". The report highlights our country's future transportation challenges and offers some recommendations to improve our infrastructure. Brookings Fellow; Robert Puentes, writes "We must recognize that we are on the cusp of a new wave of transportation policy. The infrastructure challenge of President Eisenhower's 1950s was to build out our nation and connect within. For Senator Moynihan and his colleagues in the 1980s and 1990s it was to modernize the program and better connect roads, transit, rail, air, and other modes. Today, the challenge is to take transportation out of its box in order to ensure the health, vitality, and sustainability of our metropolitan areas."

The report goes on to say, "America's transportation infrastructure has failed to keep pace with the growth and evolution of its economy. At the precise time when the nation desperately needs to prioritize its limited investments and resources, the federal transportation program has lost its focus."

In January 2009, the American Association of Civil Engineers (ASCE) released its national "Infrastructure Report Card" and gave our nation's overall infrastructure a grade of "D." Further the report card concluded we would need to spend a daunting \$2.2 trillion over the next five years to make meaningful improvements. Bridges were given a grade of "C." The report stated that more than 26% of the nation's bridges are either structurally deficient or functionally obsolete. The report went on to say that a \$17 billion annual investment in bridges would be needed to substantially improve current bridge conditions. Currently only \$10.5 billion is spent annually on the construction and maintenance of bridges.

The ASCE's "Infrastructure Report Card" proposed five measures it believes will help the country improve its infrastructure:

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- Increased federal leadership in infrastructure;
- Promote sustainability and resilience;
- Develop federal and regional infrastructure plans;
- Address life-cycle costs and maintenance needs; and
- Increase and improve infrastructure investment from all stakeholders.

This is a good list of recommendations, covering the “big-picture” or global considerations all the way down to the details or local considerations to evaluate issues to improve the sustainability of our bridges. First, looking at the big picture, the ASCE recommendations call for increased federal leadership in promoting sustainability.

To gain better understanding of the federal government’s role in sustainable bridges, I talked to Mr. Myint Lwin, director of Federal Highway Administration (FHWA) Office of Bridge Technology. Mr. Lwin has been a leader in promoting sustainability of bridges and the concept of “Green Bridges”. He says, “In ‘Green Bridges,’ the design, construction, and maintenance practices should give full consideration to at least the following areas:

- Attention to safety, durability, mobility (traffic flow), and efficiency;
- Compliance with environmental and preservation laws and regulations;
- Application of context sensitive solutions;
- Sustainable site selection and planning;
- Utilization of high performance materials and quality workmanship;
- Conservation of materials and resources; and
- Avoidance of negative impacts on the ecosystems.”

As you can see, the list of green bridge criteria is quite extensive with each one of these items worthy of much research. Simply said, this is a daunting list. To put all of these criteria into perspective, perhaps we should start by getting back to the basics.

As engineers, we are trained to develop efficient designs. This practicality comes from cost consciousness, but also from written and unwritten ethical standards aimed at protecting the public. Canon 1 of the ASCE Code of Ethics 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.”

While achieving sustainability may seem like an overwhelming task, really it comes down to all of us doing our part. We all need to be aware of the big picture, but there is much we can all do in our own arena. First and foremost, I would think “life-cycle” cost or economy should be of primary importance in bridge design. This concept is nothing new.

In 1883, the Brooklyn Bridge was completed. In 1944, some six decades after its opening, pre-eminent bridge engineer David B. Steinman wrote: “The [Brooklyn Bridge] structure did not represent the contemporary style in architecture. It had not a single battlement, a single inset of red brick or white marble, a single scroll of cheap ironwork, or a single panel of gilded decoration. But later generations clearly see what the Roeblings’ wrought. In an age of superficial embellishment and pretentious atrocities the two bridge builders gave no thought to the prevailing fashion in design. They were not architects, but workmen seeking only to do an honest and sturdy job. How the thing was going to work and how to make it last were their chief concern. So they built honestly and soundly. And sound building is beautiful building.”

In 1916, bridge designer, J.A.L. Waddell wrote in his treatise *Bridge Engineering*, “In every detail of bridge-designing the principles of true economy must be applied by everyone who desires to be a successful bridge engineer.”

In 1929, renowned bridge designer Conde McCullough argued that the economics of bridge building was “unquestionably the highest, most difficult and most important feature of bridge engineering.” McCullough is credited with some of the most elegant bridges ever built on the west coast and many of his bridges along Oregon’s coastal Highway 101 are regarded as both structural and aesthetic masterpieces. In McCullough’s bridges he strove

match his designs to each location’s unique environment. He believed that bridges should be a measured balance of both form and function. All the while, McCullough was ever mindful of not wasting the taxpayer’s money. Accordingly, he paid a great deal of attention to site conditions, stream behavior, durability, navigation requirements, traffic considerations, architectural features, and available funding. While McCullough never used the term “sustainability”, he most certainly practiced it.

Today we face the challenge of maximizing transportation funding in today’s tough economic times. We have an ever aging bridge inventory, and we have growing demand for more and more bridges. Accordingly, proper management of our bridges is essential to achieving sustainable bridge solutions on a national, regional, and local level.

To stretch our transportation funds, the ASCE has recommended development of federal and regional infrastructure plans. FHWA’s Myint Lwin has written about the importance of implementing integrated bridge management systems. He writes; “As transportation agencies are facing limited resources,... for maintaining and preserving an efficient network of highways, it becomes ever more important to invest the resources in areas where benefit-to-cost ratios are the highest.”

In the mid-1990s, Congress rescinded state’s mandatory use of FHWA’s bridge management system which is designed to prioritize bridge programs and allocation of resources. In lieu of the FHWA’s program, states were allowed to adopt their own management systems today we have most states using the AASHTO bridge management system. By states setting their own bridge priorities, their plans may have, or may not have, supported the nation’s highest priorities.

Some states have done a wonderful job of managing their bridges, and perhaps some states not so wonderfully. As funds get scarcer, Congress will most likely focus federal funding based on performance. FHWA and the United States Department of Transportation will increasingly measure the states’ bridge performance, and states will have to

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demonstrate effective use of federal funding. While there will be some funding for bridges coming from the recently passed stimulus bill, there will be more requirements on accountability and transparency.

It is important to remember that each bridge plays a role in the overall transportation infrastructure plan, and that by local communities taking a myopic approach to bridge planning, we may in fact not do the best thing for our overall transportation needs. The ASCE's "Infrastructure Report Card" recommended improving federal and regional infrastructure plans to better identify priorities and implement multi-modal strategies.

We are beginning to see this kind of "big picture/strategic" thinking being implemented in some markets. For example, Colorado's I-25 Transportation Expansion built in Denver, is an excellent example of sustainable infrastructure development. Known as the "T-Rex" project, it was a unique collaboration between the Colorado Department of Transportation (CDOT) and the Regional Transportation District (RTD) and was the nation's first multi-modal project in the nation to use the design-build delivery method. Built from 2001 to 2006, this \$1.28 billion, Kiewit Corporation-led joint venture project included the reconstruction of 17 miles of I-25 and I-225, 19 miles of new double track light rail transit lines, 13 light rail stations, three parking structures, eight interchanges, and more than 75 bridges and tunnels. With an eye to the future, the T-Rex project enhanced our nation's interstate highway system, improved Denver's regional and local traffic capacity, and added light-rail transit as a viable alternative for local commuters. Further, construction was performed in a way that minimized disruption to the public and the environment.

Missouri's "Safe and Sound" bridge initiative is an ambitious program to upgrade the state's 10,000 plus bridges. Approximately 1,100 of these bridges are in poor to serious condition. With an emphasis on safety, mobility, efficiency, and value, the Missouri DOT packaged 554 bridge replacements in a single design-build contract. This \$487 million contract was awarded in May 2009 to

KTU Constructors, comprised of Kiewit Corporation, Traylor Bros., Inc., United Contractors, Inc., HNTB Corporation and The LPA Group, Inc.

In Oregon, the state is in the middle of an ambitious statewide bridge improvement program. The goal of the program is to improve the state's aging bridge infrastructure system. As Oregon's bridges deteriorated, more and more weight limitations were placed on bridges to prevent failures. Financial projections indicated substandard bridges would cause a potential loss to Oregon's economy is estimated at \$123 billion in lost production and 88,000 lost jobs in the next 25 years unless steps were taken to improve the state's bridges.

Most recently, the third Oregon Transportation Investment Act (OTIA III) was enacted in 2003. The \$2.46 billion OTIA III allocates \$1.3 billion to repair or replace hundreds of aging state highway bridges. This work will be accomplished during the next 8 to 10 years.

Oregon is using what they call "CS³". CS³ stands for Context Sensitive and Sustainable Solutions. The goal of the program is to foster workforce development; reflect the community's cultural and aesthetic interests; maintain mobility and safety; ensure sound stewardship of the natural environment; and promote cost-effectiveness.

More and more, we see owners placing emphasis on sustainable solutions as part of a well planned infrastructure program. In planning Honolulu's new 20-mile elevated rail line that will connect West O'ahu with downtown Honolulu, the City and County of Honolulu placed an emphasis on sustainable solutions. In Kiewit Pacific's 2009 winning design/build proposal for the West O'ahu/Farrington Highway Guideway concrete piers and precast concrete guideway provided many sustainable elements and opportunity for aesthetic treatments. Kiewit's lead designer is HNTB Corporation and is supported by FIGG Engineering Group, Shannon & Wilson, Inc., including SSFM International, Inc., Yogi Kwong Engineers, LLC, and Dan Brown and Associates.

These are just a few recent examples of good sustainable bridge solutions being implemented through improved strategic regional planning.

Finally, the ASCE's "Infrastructure Report Card" also called for improving life-cycle costs and the maintainability of our bridges. These are important considerations in developing sustainable bridges. In order to improve life cycle costs and maintenance we will have to make improvements in three areas; materials, means and methods, and design. As the saying goes, "the devil is in the details," therefore the bridge community will have to roll up its sleeves and get into the details.

Materials used in bridges need to be continually evaluated and researched to make improvements. First, let me make the case for use of concrete in new bridge designs. By almost any measure concrete is a "green" bridge material. Let's look at some of the advantages of concrete as a bridge material.

- Use of Supplementary Cementitious Materials such industrial by-products as fly ash, slag, silica fume.
- CO₂ sequestration capability of concrete (ability to absorb CO₂)
- Energy cost of production: Reinforced Concrete: 2.5 GJ/t; Steel 30 GJ/t.
- Low solar reflectance compared to asphalt: Reduced Heat Island effect in urban areas.
- Recyclability of concrete and reinforcing steel.

Although in early testing, a California-based company, Colera, has developed a way to trap carbon from fossil fuel plant emissions to produce calcium carbonate cement. This process sequesters a half-ton of CO₂ for every ton of cement produced. Current methods of portland cement production produce roughly one ton of CO₂ emissions for every ton of cement produced.

Other potential advanced bridge materials may also improve the sustainability of our bridges, these include:

- Ultra-High-Performance Concrete, 25,000 - 30,000 psi with correspondingly high tensile strength
- Self-Consolidating Concrete
- Lightweight Concrete

- Sacrificial Deck Systems which allow rapid rehab (polyester concrete or asphalt)
- Improved reinforcing steels (high strength, corrosion resistance)
- Low volatile organic compound paint systems
- Carbon absorbing materials
- Use of recycled materials and recyclability of materials

In recent years, research on advanced bridge materials such as ultra-high-performance concrete (UHPC) for bridge applications has been taking place at an increasing pace throughout the United States. One such research program yielded the world's first UHPC "Pi girder" (double tee cross section) and the promise of increased bridge durability. According to Terry J. Wipf, director of the Bridge Engineering Center at Iowa State University's Institute for Transportation, "The benefits [of UHPC] ultimately should be a reduction in long-term costs associated with bridge maintenance. Furthermore, it is very likely that further advances with ultra-high-performance concrete will yield bridge designs in which the deck and superstructure last for the same duration, thus eliminating the need for intermittent and costly deck replacement."

Improvements in sustainability will also come from improving means and methods to build our bridges. Typically improved means and methods will reduce environmental impacts and roaduser impacts. Methods which will help include the use of:

- Erection Trusses;
- Balanced Cantilevered Methods;
- Pre-Fabricated Assemblies; and
- Self-Propelled Modular Transporters (SPMTs).

Currently the average life span of our bridges is about 40 to 45 years with decks replaced every 20 years. Doubling the life spans of our bridges would go a long way towards improving the overall sustainability of our transportation infrastructure and bridges. Extending the service life of our bridges will start by adopting improved design details. The following is a list of ideas to get the ball rolling:

- Simplification of details
- Adaptable substructure designs

- Consideration for bridge inspection, monitoring, and maintenance
- Allowance for future modifications and retro-fitting such as for mass transit
- Consideration of utility corridors along bridge alignments
- Appropriate focus on context-sensitive solutions

In the February 2009 issue of the magazine *Civil Engineering*, a special section was published on the "Guiding Principles for Critical Infrastructure." Written by an elite committee, the authors write, "We tend to take our infrastructure for granted until something goes wrong---often terribly wrong."

Citing examples such as the levee failures during Hurricane Katrina, Boston's Big Dig tunnel collapse, and the Minnesota I-35W bridge collapse the authors also ask some hard questions of our profession:

- Have we, the designers, the builders, and the operators of infrastructure, ignored the need to manage and communicate risks?
- Have we failed to consider critical infrastructure as part of a complex system?
- Have we failed to call for upgrades to existing infrastructure as conditions have changed?
- Have we allowed the intertwined pressures of cutting time from schedules and reducing costs to prevail over the principle purpose of our built infrastructure, which is to protect the safety, health, and welfare of the public?

Recall that the ASCE "Infrastructure Report Card" gave a grade of "C" to bridges. Twenty-six percent (26%) of the nation's bridges are either structurally deficient or functionally obsolete. An annual investment of \$17 billion is needed in bridges to substantially improve current bridge conditions.

Improving the sustainability of our bridges will not come from one change in federal regulations, from one new method of structural analysis, from one new super bridge material, from one new design detail, from one new construction method, from one new maintenance procedure, nor from one new monitoring technique. The bridge industry will not be able to meet society's needs for the

future with the industry taking a myopic view of what bridges should be. Clear vision and improved sustainability of our bridges will come from all of us in the bridge industry; owners, regulators, the public, academia, designers, and builders working together toward a common goal.

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