Making the Case for Resilient Design—Part 2

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In a recent *ASPIRE*® article, "Making the Case for Resilient Design," I argued that true sustainability cannot be measured only by our impact on the environment; we must also consider the impact the environment has on us.[1] In other words, what we think of as "green" design is only half of sustainability—the other half is resilience (**Table 1**). Resilience is an indicator of how a system responds to shock. Systems can include communities, companies, families, individuals, and physical assets. Shocks can be chronic, such as ongoing and long-term weather conditions, or acute, such as natural and human-made disasters. The resilience of our physical infrastructure is measured in terms of the infrastructure's durability and capacity to remain functional or to recover quickly regardless of the type and severity of shock.

Case Study: Seismic Resilience

I worked for several years at a San Francisco–based engineering firm whose expertise is the design of seismic-, blast-, and fire-resistant buildings and infrastructure. During my time there, the replacement eastern span of the San Francisco–Oakland Bay Bridge was completed alongside the existing span, which was more than 75 years old. I drove over the new span many times as the old steel truss structure was disassembled girder by girder. During those drives, I would think back to when, as a young engineer in San Francisco, I watched the TV coverage of the damage to the original bridge caused by the 1989 Loma Prieta earthquake, which killed one person.

Table 1. Objectives of Resilient and Green Designs

Resilient Design	Green Design
Preserve lives	Use renewable materials
Produce longer-lasting structures	Use fewer natural resources
Build stronger communities	Lower energy use
Faster economic recovery	Produce less waste
Incur less damage in disaster, therefore producing less debris	

Source: U.S. Resiliency Council

That seismic event spurred a decades-long effort to design a replacement bridge that would be built for resilience. Using sophisticated simulation analysis methods, engineers designed the bridge and its approach spans, which were constructed from segmental concrete box girders, to meet the severe ground motions that would be expected in an event comparable to the Loma Prieta earthquake or the even more powerful 1906 San Francisco earthquake. The bridge typically sees traffic of about 260,000 vehicles daily. Consequently, the resilience of the entire Bay Area and the region's capacity to recover after a major disaster are both highly dependent on the ability of this bridge (and others) to remain safe and usable. As the California Department of Transportation's Brian Maroney explained to a reporter in 2013, "The [new] Bay Bridge is built for those motions we expect to occur once every 1,500 years."[2]

Social and Economic Benefits of Resilient Design

In a 2010 Department of Homeland Security report on the aging U.S. infrastructure, one contributor wrote, "Resiliency is the foundation of preparedness.... A resilient society can face the challenges of the upcoming decades."[3] Unfortunately, the transportation infrastructure (our nation's roads and bridges) is often taken for granted. We only have to look to the Interstate 35 West bridge collapse in Minneapolis, Minn., in 2007, or collapses caused by flooding or landslides such as in Cedar Rapids, Iowa, and Big Sur, Calif., to see that, while often ignored, the performance of bridges is an essential link in the chain that allows a community to function during and following natural or accidental disasters.

Whereas a building might house 1000 people, a bridge might serve 1000 buildings. The centrality of our bridge infrastructure to the functioning of our communities before and after a disaster means the resilience of these assets is a social and economic imperative that goes far beyond the potential costs of maintaining or replacing bridges if they are damaged in such a disaster.

The concrete industry's efforts to make the case for concrete bridges by using the prevailing mindset that sustainability is about "green" design is not new. For example, in a 2009 presentation for the Construction Research Congress, Raymond Paul Giroux stated, "By almost any measure concrete is a 'green' bridge material." He went on to cite some of the advantages of concrete as a sustainable bridge material, such as the lower energy cost of production per unit mass of concrete compared with steel (2.5 GJ/t and 30 GJ/t, respectively), low solar reflectance, and recyclability of concrete and reinforcing steel.[4]

One of the U.S. Resiliency Council's most important missions is to encourage owners, builders, and governments to extrapolate the value of resilient design beyond the confines of first costs, long-term maintenance, and green design. The value of resilient design is realized only when we fully quantify the benefits it has for society as a whole. An important consideration for the concrete industry is to develop ways to quantify the social and economic benefits of concrete structures in terms that decision makers can use to justify the selection of a structural system. In a Perspective article in the Spring 2019 issue of *ASPIRE*, Jeremy Gregory of the Massachusetts Institute of Technology made a strong case for the industry's ability to measure the resilience of bridges and encouraged readers to rethink how we describe sustainability. According to Gregory, "Many aspects of a structure, including its future economic impact and the environmental consequences of construction, repairs, or replacement, affect its sustainability. Our research finds that quantitative assessment of these factors can lead to alternatives that improve a structure's sustainability."[5]

Making the Economic Case for Resilient Design

To calculate resilient design's return on investment (ROI), bridge designers and builders can use available analytical and engineering tools. The straightforward equations, starting with that used to calculate risk, are:

$$Risk = Probability \times Vulnerability \times Consequence$$

It is important to decision makers that risk be an objective and quantified metric that allows for direct comparison of strategies, investments, and outcomes. Probability is the likelihood over the life of a bridge that a natural or human-made hazard event will occur. Vulnerability is the resulting damage and loss of function that the bridge will incur when subjected to that hazard. Consequence is the cost to repair that damage as well as the lost social and economic output caused by the loss of the bridge for a time.

The ROI is the savings in risk achieved through resilient design divided by the additional cost, if any, to achieve that resilience:

$$ROI = \frac{Risk_{Standard\ Design} - Risk_{Resilient\ Design}}{Cost_{Resilient\ Design} - Cost_{Standard\ Design}}$$

The ROI of resilient design is a metric that all government entities should use to evaluate new bridge projects. Often, however, they don't operate in these terms; instead, they focus on what is the lowest bid that meets the minimum project requirements. Moving beyond this short-term assessment standard is imperative for the long-term health of our communities.

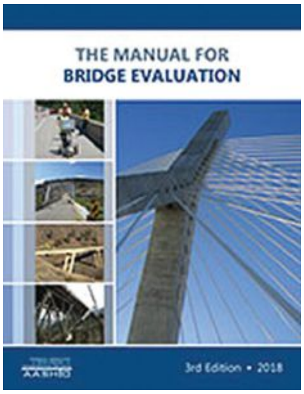
The U.S. Resiliency Council encourages the bridge and transportation industries to invest in research that quantifies the performance of bridge structures in natural hazards. This is the first necessary step to making the case that using resilient materials such as concrete more than pays for itself in the short and long term by reducing the social and economic impacts of disasters on the communities served by these structures.

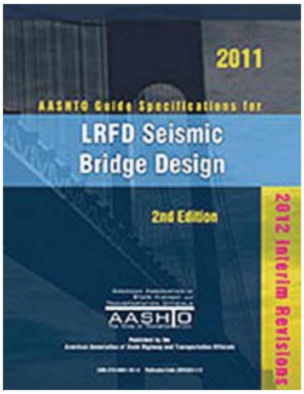
Conclusion

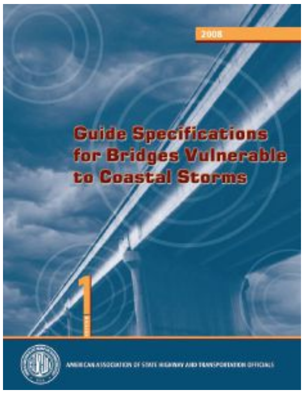
The COVID-19 pandemic is clearly the largest and most difficult challenge to face our country in many decades. We must take advantage of the opportunity it has afforded us to think more deeply about the inevitability of natural and human-made hazards and the need to invest in resilience and preparedness. It is a matter of when, not if. Because our transportation infrastructure is expected to last at least 50 to 100 years, society today must not have a short-term outlook on the challenges we will face tomorrow.

References

1. Reis, E. 2020. "Making the Case for Resilient Design." *ASPIRE* 14(2): 6–7.
2. Cabanatuan, M. 2013 (September 1). "Bay Bridge Made to Withstand Major Earthquake." SFGATE. https://www.sfgate.com/bayarea/article/Bay-Bridge-made-to-withstand-major-earthquake-4778622.php.
3. Erickson, M.D. 2010. "A Bridge to Prosperity: Resilient Infrastructure Makes a Resilient Nation," in *Aging Infrastructure: Issues, Research, and Technology*, 2-28–2-55. Buildings and Infrastructure Protection Series 01. Washington, DC: U.S. Department of Homeland Security. https://www.dhs.gov/xlibrary/assets/st-aging-infrastructure-issues-research-technology.pdf.
4. Giroux, R.P. 2009. "Sustainable Bridges." Presentation at the Construction Research Congress, "Building a Sustainable Future," held in Seattle, WA, April 5–7, 2009. (Reprinted as a supplement to Giroux, R.P., 2010. "Sustainable Bridges: A Contractor's Perspective." *ASPIRE* 4(2): 12–13.)
5. Gregory, J. 2019. "Quantitative Assessment of Resilience and Sustainability." *ASPIRE* 13(2): 10–11.







EDITOR'S NOTE

Our community of bridge professionals has systematically responded to extreme events for decades with deemed-to-satisfy and probability-based specifications that fill knowledge gaps in the technical arena. Evan Reis has now presented a holistic approach that moves beyond the last decade's sustainability concepts. The new concept of infrastructure resiliency is emerging as a holistic view that also considers risks and community impacts. Bridge professionals need to understand this much broader framework and then become engaged with leadership to help frame the ongoing conversation.