Building Better Bridges

Paul Giroux

Let the Debate Begin:

The tragic collapse of the I-35W bridge in Minneapolis on August 1, 2007 will undoubtedly leave indelible images in our minds. Even as recovery efforts continued, Minnesotans turned their attention towards rebuilding the bridge and the debate began on what kind of bridge should be rebuilt in various debate forums, including web based blog sites. Reading a sampling of the posted opinions on what to build highlights the wide range of opinions society has about its bridges:

> **Sean says:** I wouldn't mind if the new 35W bridge were to be simply a deck with piers holding it up… Too many works of art is too much of a good thing… Art is also strongly subjective.
> **Froggie says:** The bottom line is we need to get a replacement bridge. Sure, aesthetics should be included if at all possible.
> **Mulad says:** I don't think we need to do something that makes a huge statement like the Sunshine Skyway. However, since it's so close to the Cedar Ave Bridge, I hope designers find a way to make the two bridges complement each other.
> **Scott B says:** Function over Form, I say. If the bridge can get me safely across the Mississippi on 35W, build it and let's move on.
> **Elsa says:** Although I agree we need to be fast and economical while building the new bridge, I think the new bridge should look good, too.
> **Botski says:** Function over Form is what gives us brown box eyesores otherwise known as strip malls. A little art and beauty is good for the human soul.
> **Barry says:** A safe design is good for the human soul, too. I suggest a well-designed, sturdy structure first… Then we can art it up later, when our state comes to its senses and decides that quality-of-life really wasn't such a bad idea after all.
> **DizzyInCircles says:** I would really like to see a cable-stayed or suspension bridge of some type.
> **Erin says:** I think it absolutely should be beautiful and a work of art as a memorial to the victims.
> **John C says**: I am deeply concerned about those who decry a "beautiful" bridge. Of course it should be beautiful. Beauty is the highest calling of a society. A cable stay bridge would be most beautiful. Let's be the best in Minnesota again.
> **Brent says:** The new bridge should be designed in such a way that it will become a Minneapolis/Minnesota landmark. What a great area asset it would be if Minneapolis had a bridge of comparable stature to the great bridges of the world…ie Golden Gate, Brooklyn Bridge, Tower Bridge in London.
> **KC says:** For what it's worth - I thought the I-35W bridge was beautiful, especially from the bike path below. The structure was so delicate and light compared to the other bridges.
> **Eric says:** The structure was so delicate and light compared to the other bridges. Indeed. So delicate and light that . . .

To address the varying desires of the public, the Minnesota Department of Transportation solicited proposals for a replacement bridge from contractors and opted to rate proposals on a cost plus schedule or "A+B" formula that also included a technical score which rated many criteria including bridge aesthetics. This formula in theory could make it possible for the highest price / longest duration schedule proposal be the winner. This is in fact what happened on September 19, 2007 when the Minnesota DOT announced that a Figg Bridge Engineers design proposed by the team of Flatiron/Manson was the winning proposal.

Minnesota DOT's choice of Flatiron/Manson was quickly protested by local contractors C.S. McCrossan and Ames/Lunda who had offered to build the bridge for about $50 million less than Flatiron/Manson and with shorter schedules. They are claiming the Minnesota DOT "misdirected" them about what the state wanted in the replacement bridge. Famed Spanish architect, Santiago Calatrava (partnered with a Walsh/American Bridge team) also voiced his frustration with the bidding process in a letter to Gov. Tim Pawlenty.

On October 8, 2007 Minnesota officials elected to dismiss the protest of the unsuccessful bidders, and unveiled the winning design. Initial response to the design has been favorable, yet some question if the public is getting the best value.

Many prominent so-called "signature" or "landmark" bridges have been built in the past 75 years in the United States, and many more are currently being built or are on the drawing boards. I am fascinated by the unique challenge of designing and building signature bridges. That is, the challenge to find the right balance of aesthetics (form) and performance (function).

As I talk to many bridge industry people I sense a lot of pride in what we've all accomplished. Yet, I also sense a lot of frustration. Frustration with the politics, how the selection process works, how long the process takes, inaccurate budget estimates, constructability and durability, and certainly frustration with the ultimate cost of signature bridges.

In the following, I hope to highlight some of the unique challenges and issues we all face in the signature bridge market. It is not my intent to be critical of owners, designers, or contractors, nor is my intent to be critical of any specific firms or individuals. To be sure, there is always "more to the story" when it comes to controversial projects and the examples I cite are only to highlight the complexities of this issue. It is however, my intent to generate meaningful dialogue within our industry with the goal of building better bridges. And, I am confident we can build better bridges.

Society's Love Affair with Signature Bridges:
To be sure, signature bridges play an important and unique roll in modern society as icons of their communities. Even in 1883 architectural critic, Montgomery Schuyler wrote of John Roebling's Brooklyn Bridge:

"It so happens that the work which is likely to be our most durable monument, and to convey some knowledge of us to the most remote posterity, is a work of bare utility; not a shrine, not a fortress, not a place, but a bridge."

The demand for major bridges to be more than just spans, but also monuments continues today. A sampling of recent bridge news events highlights society's ongoing love affair with signature bridges and the pressure on cities and states to build them.

The 1989 Loma Prieta earthquake severely damaged the existing east span of the San Francisco Oakland Bay Bridge (SFOBB) and Caltrans was tasked to decide whether to retrofit or build a new span. Caltrans eventually concluded replacement of the existing structure was the answer and recommended a practicable design be built. Local Bay Area politicians complained about Caltrans' unattractive proposal, calling it a "freeway on stilts". An editorial in a Bay Area newspaper added, "the design [aesthetics] of the bridge is more important than the cost".

In June of 1999, Dallas, Texas, the Dallas City Council authorized support for the concept of "signature bridges" and design enhancements for bridges across the Trinity River. And, in July 2006, Dallas Mayor Laura Miller told city leaders who gathered as work was to begin on the first of the three bridges designed by Spanish architect Santiago Calatrava, "Today, we break ground on our Eiffel Tower" and "Once we start, there will be no stopping." Senator Kay Bailey Hutchison, added; "The vision of the Trinity River Corridor will transform and improve the Dallas landscape…".

After surviving the "Y2K" scare, western New Yorkers set their sights on the controversy of the new Peace Bridge. Then U.S. Senator, Patrick Moynihan concluded after weighing options for the new span, "A new bridge over the Niagara could become for Western New York what the Golden Gate has become for San Francisco's Bay Area; a new gateway, a defining moment of entry. To reach Buffalo or Fort Erie over the Authority's dull trestle when one could otherwise soar across on a bold new single-span would be rough justice for anyone who had the opportunity to imagine what could have been." One concerned citizen summarized the controversy. "There's a current feeling about the existing bridge. Some people don't feel the American side and the Canadian side have equal aesthetics."

To help solve this dilemma, in October 2002, Swiss bridge designer Christian Menn was brought to Buffalo as a "visionary". He was asked to recommend a solution, using whatever bridge type he chose, "with no limits". After years of effort, a binational design jury selected a Menn inspired twin-tower cable stayed bridge. Local press hailed the decision in December 2005, stating: "Many people have not understood the value of building a beautiful bridge. But there is no place where that is more vital than Buffalo. This region suffers from its snow-bound reputation, which can translate into people not wanting to move and live here. No one comes or stays because of a bridge design, but it can help project a modern, vibrant, active sense of place that can attract people and make everyone prouder to live here."

In December of 2002 Delaware Governor Ruth Ann Minner commented on the proposed new Indian River Inlet Bridge. "The inlet – and Delaware's entire seashore – are among our state's most precious and popular natural resources. We want a bridge that adds both beauty and functionality for vehicle, bike and pedestrian traffic. And we want it to compliment the natural landscape and the recreational facilities enjoyed by our citizens and visitors."

This is just small a sampling of the comments you may hear or read today regarding plans for new bridges. I mentioned Oakland, Dallas, Buffalo, and Delaware, yet many other places including St. Louis, Louisville, Cleveland, Toledo, and Omaha, have recently been through, or are in the process of selecting "signature" bridges. And, I'm sure if you researched these, you could find similar comments from the politicians and the public with respect to what a bridge should be, or shouldn't be. If there is one thing you can bank on, it's that signature bridges are not going away. Iconic bridges are part of the fabric that makes up their communities and society will continue to want them.

Form vs. Function:
A bridge by **function** could be defined as a structure spanning and providing passage over a gap or barrier, such as a river, ravine, or roadway. Obvious functional factors that effect bridge design include; site conditions, load capacity, span lengths, span widths, vertical clearance, seismic criteria, scour criteria, service life, maintainability, constructability, and life-cycle cost. 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. Clearly when a bridge is designed with functionality as a priority, its form follows its function.

Conversely, when a bridge is designed with aesthetics as a priority, its function follows its form. One need only read some recent press releases to find evidence that society is placing an inordinate and perhaps unwarranted emphasis on aesthetics or **form**, selecting designs that are "graceful", "striking", "magnificent", "majestic", and "beautiful" that provide a community with its own Eiffel Tower or Golden Gate. Essentially, society wants their prominent bridges to be monuments; grand sculptures, that will provide their city an icon for all of time. Let's all hope we don't see the day when a bridge was selected for being "sexy" or "groovy". Although, recently I did read where one citizen recommended naming Maine's new Penobscot Narrows Bridge, "The Wicked Good Bridge".

Personally, I would like to read a selection committees recommendations and see their primary selection based on functional criteria such as service life cost, and describe their selection with terms like, "seismically sound", "efficient and maintainable", "tough and durable", and "financially viable".

Don't get me wrong, I am not anti-aesthetics. In fact, I admire and respect the many great bridges built in the U.S. in the past which in my estimation properly balance form and function. As far as designers, one of my personal favorites is Conde McCullough. He once said: "From the dawn of civilization up to the present, engineers have been busily engaged in ruining this fair earth and taking all the romance out of it." Clearly Mr. McCullough backed his words with action, and in my view, his bridges along the Oregon Coast on Highway 101 are a great example of balancing form and function.

This battle, the tug-of-war between form and function is nothing new. Joseph Strauss, the Chief Engineer on the Golden Gate Bridge, originally envisioned a newly patented "cantilever-suspension" bridge for the crossing. Fortunately, he also felt a "suspension" type bridge should be evaluated and requested Charles Ellis and Leon Moisseiff to prepare plans. Eventually, the suspension bridge option was selected and Strauss brought in local architect Irving F. Morrow to provide not only political and financial support for his bridge design, but also its world-famous aesthetics and art deco flair.

So, a bridge by *function* could be defined as a structure to span a gap and to provide passage. And, a bridge by *form* could be defined as work of art, to span time and provide an icon for the dreams and visions of a society. Thus; the tug-of-war, as we endeavor to make our bridges all things to all people.

Function Dominated Historic Bridge Design:
Let's give our due to, Messrs. Howe, Pratt, and Warren (truss designers). Senator Moynihan's lamenting if he'd have to "reach Buffalo or Fort Erie over the Authority's dull trestle" speaks volumes about society's lack of respect for the back bone of our national transportation infrastructure, that is the everyday, standard railroad and vehicular bridges that carry the bulk of traffic in this country. In Frederick Gotttemoeller's book, "Bridgescape", he calls these standard bridges the "workhorse" bridges.

When would the 1,776 mile Transcontinental Railroad have been completed if we relied on focus groups and outreach meetings to select the bridge designs? Thank goodness for the young, brave engineers from schools like Rensselaer Polytechnic Institute and Union College who braved the wilderness in the 1860's to design and build the "dull trestles" necessary to open up the west.

And, when would our nation's 46,700 mile long interstate highway system have been substantially completed if we waited for ten design concepts for every major bridge? Started in 1956, I venture to say we still might be traveling Route 66 instead of I-40.

There are over an estimated 580,000 bridges in this country. Most of these are small or medium size workhorse bridges with spans less than 500 feet. These are the bridges you probably don't even notice as you're zooming down the turnpike, talking on your cell phone, and sipping a latte. But, they are there. They are there day and night, 365 days a year silently and unceremoniously doing their job; carrying people to home, to work, and to play. They are there carrying our freight and provide the life line for our agricultural and industrial output.

So, for each age we must build bridges appropriate for our needs and what we can afford, as efficient and inexpensive transportation is the fuel that drives our economy.

Signature Bridge Economics 101:
It is difficult to compare unit costs of one bridge to another as each bridge has a unique foundation and superstructure design, and potentially wide variations in labor, equipment, and material costs. However; in current dollars, a basic short or medium span steel girder or prestressed girder bridge can be built for $100 to $200 per square foot of deck area. By comparison, a sampling of cable stayed bridges built over the past twenty years shows the range to be more like $400 to $800 per square foot of deck area. In some cases this increase in cost is warranted due to site conditions and span lengths.

Much of our historic signature bridges were driven by functionality and efficiency. Today, most if not all of our nation's bays, rivers, and gorges have already been bridged, so where does society build their new signature bridges?

In some cases new signature bridges are being built to replace existing "dull" bridges that are now functionally obsolete. In other cases new signature bridges have been built parallel to existing spans to add traffic capacity. And recently, there have been some new bridges necessitated by homeland security issues, such as the Hoover Dam by-pass. However, most bothersome to me is evidence of efficient road alignments being purposely altered on to more difficult terrain to provide dramatic stages for signature bridges.

When we design a bridge, site conditions, load rating, span lengths, span widths, vertical clearance, seismic criteria, scour criteria, aesthetics, life-cycle costs, maintainability, and constructability all need to be evaluated.

Setting aside aesthetics for a moment, if we were to take all of these remaining variables and rationally evaluate them, we could generate numerous practicable bridge designs for a given location. Going one step further, if society placed an emphasis on service life and service life cost, I would venture to say that most of the major bridges we are building today would look much different.

Yes, many of the current signature bridges may not look the way they do, but I have to believe they would have been less costly to build and they'd ultimately have a lower service life cost. This leads one to ask the question, how much should we pay for aesthetics?

In Oakland, Californians opted to dismiss Caltrans' "freeway on stilts" and were willing to pay over $4,500 per square foot of deck area on the new self-anchored suspension span (SAS) signature span being built as part of the new SFOBB. By comparison, the adjacent linking structure, the "Skyway" which leads up to the SAS was built for around $1,000 per square foot of deck with much of its ultimate cost tied up in its state-of-the-art foundations. Site conditions and navigation considerations at the SAS site do dictate

some incremental increase in cost over the adjacent Skyway; however, you would have to conclude that Californians were willing to spend about an extra $3,000 per square foot for aesthetics. Translated, that's a whopping $1 billion dollars for aesthetics on the SAS. But it's not all for good looks, there's also an expensive cantilevered pedestrian walkway / bicycle path to provide passage from Oakland to Yerba Buena Island. Christian Menn, the distinguished Swiss bridge designer termed the SAS an "architectural bridge," that is one whose design is driven by form, as opposed to functional criteria such as structural and constructional considerations.

History will judge the value the East Span of the SFOBB and other new signature bridges. It is arguably admirable to have this vision today for a better bridge for society tomorrow as the worth of a signature bridge to society is incalculable. David Billington, a professor of civil engineering at Princeton authored the book, *The Tower and the Bridge.* Many signature bridges are in Billington's view "structural art". 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." Admittedly, the worth of a signature bridge to society is impossible to quantify, however as we build new bridges, let's ensure we are giving future generations the most value for our bridge dollars. Billington writes; "Minimum cost (economy) is an essential discipline for the creation of structural art. Economy stimulates creativity. Without the discipline of cost there can be no structural art."

Problems arise when selection committees pick a bridge design. Why? Because, in most cases when a bridge is selected the design is generally conceptual and nowhere near complete. In fact, the design may only be 20% complete. Now, I will admit to buying more than my fair share of cars, based solely on sporty good looks (and the color red), ignoring things like warranty and gas mileage. So, I accept the fact that we're all human and we'll be swayed by aesthetics. The negative consequences of my car selections are limited. However, the consequences of irrational bridge selection are potentially severe, saddling future generations with potential emergency repairs, retrofits, premature replacement, and unnecessary debt.

Once a bridge concept is selected the "design" literally becomes the law and the engineer has to "make it work". For the most part, many features of signature bridges like unnaturally curved shapes, and tapered or leaning pylons are not compatible with efficiency of design or constructability. In reinforced concrete bridge design major problems that arise from this approach may include heavily congested elements, extraordinary fabrication or placing tolerances, and perhaps even flawed erection sequences.

Another potential downside, although admittedly hard to predict is, to what degree do areas of reduced concrete cover in heavily congested zones of rebar and post tensioning have on the ultimate service life of the structure.

So while there should be caution when viewing signature bridge's abilities to achieve their ultimate life-cycle costs, today's current emphasis on aesthetics coupled with increased load capacity and other criteria have an immediate down side. Why, because, as designers pile in more and more reinforcing steel and post tensioning into structures, construction engineers and contractors struggle to find ways to fit it all in and build the structure.

We're Not Building Your Grandfather's Bridge Anymore:
Today's modern post-tensioned technology and improved concrete mixes have allowed reinforced concrete bridges; more specifically, concrete segmental bridges to be pushed to ever higher levels of performance, with higher load ratings, longer spans, and increased durability.

There is always much to be learned as any technology explores new territory. To advance the segmental bridges industry, the American Segmental Bridge Institute (ASBI) was founded 1989 to provide a forum where owners, designers, constructors, and suppliers can meet to improve the design, construction and construction management procedures, and the quality of concrete segmental bridges. As a result of ASBI, its committees, and members, many advances and improvements have been made in the segmental industry.

Yet, there are still many problems to solve as we strive to balance form and function. In addition to functional improvements from recent advances, new technology and methods have also allowed designers to push bridge aesthetics into new territory. Understandably, as the public admires the elegance and clean lines on a modern signature bridge, they are oblivious to the internal workings of the structure. Beneath the surface of the concrete lay a dense maze of precisely placed reinforcing steel and post-tensioning duct that inevitably cause major difficulties with the constructability of these structures.

In some bridges, it is not unusual to now see structural zones in bridges with reinforcing steel (or rebar) densities over 1,000 pounds per cubic yard (lbs/CY), plus densely placed post tensioning (PT) duct which can be very difficult and expensive to construct. Some designers have argued that rebar density alone should be enough of an indication to alert the contractor that the rebar/PT might be difficult to install. This is not the case. My studies show that a designer can go over 1,000 lbs/CY in rebar density and still provide all of the requisite rebar / PT fabrication and installation tolerances required by governing standards such as AASHTO, ACI, and PTI. Further, my studies also show that some designs with densities as low as 200 lbs/CY just won't work. So, when evaluating the constructability of aesthetically forced shapes in structures, don't be fooled by rebar density alone, the problem is much more complex than that, and in many cases not a problem understood by engineers, or detected by sophisticated owners or contractors in short review periods.

When an owner selects an intuitive bridge structure such as a steel girder, steel truss, or an AASHTO girder bridge design; it is possible for the design engineer to quickly develop an efficient design by checking and modeling various design iterations. In

straight forward structures, structural analysis is intuitive and so the design optimization process is limited to a finite set of iterations. Accordingly the effort required to study various design iterations is worth the time and money as it generally yields savings in the cost of building the structure.

However, in uniquely shaped signature bridges, the flow of forces is not always intuitive and the structural analysis of the structure for can be very time consuming. Accordingly, in a design optimization process it can become prohibitively expensive to keep making changes to the design and rechecking the structural analysis. This is particularly true in post tensioned / reinforced concrete structures where there can be an infinite number of ways to manage the stresses in the structure with various rebar and PT configurations. Each scenario of rebar and PT is very complex. Because of rebar and PT complexity, constructability reviews are extremely time consuming and difficult.

Once, a designer selects a final rebar and PT plan, effort needs to be made to ensure it all fits. Rebar is generally placed in horizontal and vertical orientations, while PT generally follows draped alignments. So, in heavily reinforced and post-tensioned structures the natural orientations of the rebar and PT are often in conflict and create a complex three-dimensional puzzle. Therefore, it takes a tremendous amount of time and effort to ensure a design is constructible. Design firms, generally face lump sum or limited scope budgets, so their designers can only take constructability reviews so far before the budgets are exhausted.

It is possible for designers to develop high density designs that are still constructible, but in many cases we see over simplification of complex zones ("rebar not shown for clarity") on contract drawings. All of this cramming and jamming of rebar and PT often dictates fabrication and installation of these elements to exacting tolerances. Even a layman appreciates higher precision costs more time and money. And, we all know it is cheaper to fix the design "on-paper", yet in some cases we've seen examples where designers were unable to make their designs provide standard industry tolerances. Failure to fix a design on-paper, does not mean a design is un-constructible, however it usually necessitates more expensive custom installation of rebar and PT in the field.

Recently, we've seen a trend for extraordinary construction engineering simply to prepare rebar fabrication and placing drawings during construction. A task that was once relegated to a rebar detailer, now in many cases has to be done with highly experienced engineers using sophisticated computers and software. In some extremely congested designs it may require as many or more engineering man-hours to figure out how to detail the rebar and PT as the designer spent on the original design.

Bottom line, for anyone; owner, designer, or contractor to make assumptions and interpolations on feasibility of design and construction in a conceptual phase of development is at best ill founded, but potentially project threatening.

Erection sequences for high-tech bridges are also extremely complicated and require a detailed structural analysis for each incremental step in the construction process to ensure the structure does not become overstressed during erection. One advantage to a well designed segmental bridge and well planned erection sequence is the elimination of expensive temporary falsework. Yet, some signature bridges are so exotic in form that they are not self-supporting until they are fully complete. For example, the SAS portion of the new SFOBB will require as much steel in temporary falsework as the permanent SAS structure.

Why the problem now? As I see it, at the same time we are letting an over-politicized, aesthetics-focused process control bridge selection, our designers are faced with the challenge of increased design loads. For example, twenty years ago, one out of every fifty bridges was designed to accommodate a 90,000-lb (HS-25) load. It is now estimated that one in five bridges are now designed for an HS-25 load. Seismic loads have also increased over the past twenty years. Accordingly, our designers face the challenge of creating the most elegant, yet most robust bridges ever built.

Also, it seems that in some cases civic pride or engineering egos also drive the desire to make bridge structures the "EST" of something; the long**est**, the wid**est**, the tall**est**, and so on. Boston's new Zakim / Bunker Hill Bridge is the world's wid**est** asymmetrical cable stayed bridge. In the future to tag a bridge the "EST" of something, more selection criteria will be needed. Can we one day look forward to seeing the world's wid**est**, asymmetrical, super-elevated, high-performance concrete, cable stayed bridge? Recent bridge initiatives indicate some communities may be happy with the label of the costli**est.**

So, What Do We Do?

Interestingly enough, as I have posed this question to many in the bridge world, I often get some ideas, but never a set of definitive steps, and often disagreement in how to improve the delivery of signature bridges. However, most parties agree that the process is too political. That is, the intense societal pressure for iconic bridge structures which can lead to emotional rather than rational decision making.

We are a proud and affluent society and we feel the need to demonstrate our civic pride through signature bridges. So we must face the fact that signature bridges are not going away. However; as we stand today, selection committees with the best of intentions in many cases continue to blindly march ahead on bridge designs driven to a large degree by aesthetic considerations.

This needs to change. I guess if I had to summarize my thoughts and the comments I have received they would fall into the following categories:

- Depoliticize the Process
- Training and Education
- Learning from our Past
- Realistic Constructible Details
- Informed Bridge Selection: Form and Function
- Maintain what we build

Design Does Differ from Politics:
Engineers are taught and trained to develop efficient designs. This practicality comes from cost consciousness, but also from written and unwritten ethical standards aimed at protecting the public. The American Society of Civil Engineers' (ASCE) Code of Ethics says in part that; "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." Sustainable development is the challenge engineers 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 the future.

It is because of the stewardship of engineers and their sensibilities that they strive for efficient design of structures. Admittedly, a sustainable or sensible approach may lead to "dull" bridges. However, a good engineer given aesthetics as one of many design criteria can properly balance form and function.

Conversely, when engineers are forced into making a design work to meet the bold visions of a politically driven process, sustainability and common sense may take a back seat. Many of the current designs for signature bridges are driven by well-meaning yet unknowledgeable politicians and citizens. Bridge selection and advisory committees can be comprised of city council members, planning commissioners, local business people, environmental groups, historic preservationists, and other interested parties. Some communities also use design charrettes as a forum to introduce their project to the community and solicit yet more opinions on design concepts and aesthetics.

Canadian bridge designer and educator; Dr. Paul Gauvreau, writes of the recent trend to minimize the engineer's role in the signature bridge process in his paper, *"Teaching Bridge Design in the Grand Tradition of Modern Engineering"*. He writes, "The current situation with regard to bridge aesthetics…is characterized by increasing disregard for the contribution of engineers to the definition of the aesthetically significant aspects of bridges, in favour of architects and lay people. It is wrong for engineers to be relegated to a purely technical support role based on dogmatic beliefs or political expediency. In so doing, owners deprive themselves of the richness of the engineer's unique vision, founded in the discipline of structural efficiency and economy."

Perhaps a wide open democratic process is necessary, but it can lead to many problems including; uninformed decision making, prolonged project delivery times, gridlock, higher ultimate cost, and less value for our bridge dollars.

Area leaders in St. Louis have been trying for more than fifteen years to find a solution for easing traffic flow across the Mississippi River. After years of political wrangling, conceptual bridge designs were eventually prepared. Current estimates for the bridge are nearly $1 billion which has caused disagreement between Missouri and Illinois officials on how to pay for the bridge. In January 2007, St. Louis Mayor Francis Slay told a panel of national transportation experts that he doubted a new, signature Mississippi River Bridge "will be built any time soon."

In the early 1990s, traffic tie-ups on the existing Peace Bridge between Buffalo and Fort Erie demanded more lane capacity. Initiatives for a new bridge took hold and by the late 1990s a design was developed for a new twin span adjacent to the existing 1927 bridge. This design was completed and put out for bid. Within weeks of the bid date, and after contractors had spent millions estimating the new bridge, local, state, and international politicians killed the "dull" twin span concept and it was never built. So, after years of politically charged meetings, in late 2005 a Christian Menn inspired twin towered cable stayed bridge was selected to be designed and built. By the time the ribbon will be cut on the New Peace Bridge, it will have been twenty years from the initial perceived need for a new bridge.

And, then there is the new east span of the San Francisco Oakland Bay Bridge. After the existing span was severely damaged in the 1989 Loma Prieta earthquake, the process to retrofit or replace the old bridge began. Current completion of the new bridge is targeted for about 2013, nearly twenty-five years after the earthquake.

These are just a few of the recent bridge initiatives in the United States which have been mired in a political morass. There is a huge potential cost impact to the over politicalization and extended duration of any major capital spending project including signature bridges. Certainly road user benefits and inflationary pressures should be evaluated and incentive enough to move quickly when a need is identified. However, recently we've also witnessed the risks associated in delaying projects, facing hyper-escalation of steel and cement prices in global construction commodity markets.

Politics shouldn't be confused with oversight from the government and the fine work done by the United States Department of Transportation (USDOT) and the Federal Highway Administration (FHWA) who are charged with keeping our roads and bridges safe.

Back to School:
We need to harness our passion and pride for building bridges and commit ourselves to learning everyday. We need to learn from one another. Architects, engineers, and contractors all need to understand each others work and what others can and can't do. Throughout the history of bridge building, many scholars and practitioners have concluded that in order to properly balance form and function that a holistic approach must be used. In the 1930s, architect Aymar Embury II was involved in design of the Bronx-Whitestone Bridge and called for more understanding between architects and engineers saying, "Engineers should be good architects, and architects good engineers!"

In 1486 Leon Battista Alberti said: "The greatest glory in the art of building is to have a good sense of what is appropriate. For to build is a matter of necessity; to build conveniently is the product of both necessity and utility; but to build something praised by the munificent, yet not rejected by the frugal, is the province of an artist of experience, wisdom, and thoughtful deliberation."

Trends in modern signature bridge design have been for engineers to explore the abilities of new methods and materials, and for architects to explore new shapes and forms. To truly build an efficient, yet elegant bridge we must achieve the appropriate balance of form and function. Billington writes about efficiency, economy, and elegance as necessary elements to building structural art: "The disciplines of structural art are efficiency and economy, and its freedom lies in the potential it offers the individual designer for the expression of a personal style motivated by the conscious aesthetic search for engineering elegance."

It only makes sense that a balanced, holistic approach to bridge design is essential to building great bridges. This means that engineers must learn aesthetics. Gottemoeller writes, "Aesthetic ability is not some mysterious quality bestowed by fate on a fortunate few. Though many engineers are not well prepared by their education or experience for the visual aspects of their responsibilities, they can learn what makes bridges attractive and they can produce beautiful bridges." He also says that: "Engineers have accepted a responsibility to society for bridge design. For that reason, no engineer would knowingly build a bridge that is unsafe. For the same reason, no engineer should knowingly build a bridge that is ugly."

As engineers may struggle with aesthetics, architects may struggle with making bridges efficient, practicable, and constructible. Gauvreau writes in his paper, *The Three Myths of Bridge Aesthetics*; "Architects (and other visual professionals) deal with the arrangement of abstract and visual forms. There is very little in their training, day-to-day experience, and overall perspective that equips them or inclines them to work effectively in a medium which seeks to give meaningful expression to loads, equilibrium, and forces." Accordingly, architects need to learn the basics of structural design and constructability.

Owners and selection committees need to go back to school too. Early in the development of a bridge, owner's and selection committees need to commit themselves to learn all they can about bridges. They need to learn about aesthetics, design, maintainability, and constructability. They also need to temper their initial excitement over exotic designs with common sense and long-term thinking if they are to truly achieve efficiency, economy, and elegance.

Industry associations such as, AASHTO, ACI, PTI, AISC, AWS, and ASBI have made great strides in the past to advance the science and art of bridge building and these efforts need to continue. Other organizations such as the Transportation Research Board (TRB) and its Subcommittee AFF10 (1) on Bridge Aesthetics should be monitored as they currently plan to issue a circular by the spring of 2008.

In our educational system it is not unusual for our engineering instructors to spend most of their careers in academia. The pressures of the tenure track; teaching, research, and publishing leave little time for gaining experience working in design firms or seeing the work be built in the field.

Likewise, our engineering schools turn out design engineers that design our bridges. And, in our system it is not unusual for designers to spend most of their careers only designing. I can't tell you how many design engineers I have met over the years who have never been in the field seeing their designs built with their own eyes. So let's require professional engineers to spend an appropriate amount of time in the field building high-tech signature bridges if they are going to design them. We don't allow heart surgeons to perform complicated procedures after only completing text book training, they have to go through an extensive residency program. Just as a surgeon must learn their trade by actually doing the work, so should a designer have spent enough time in the field to understand what is constructible, what isn't, and think hard about cavalierly throwing a note on a drawing directing a journeyman ironworker to field bend or adjust 1-3/8" diameter (#11) reinforcing steel bars.

And then, there are the builders. These are mixture of people, many with civil engineering backgrounds, some with construction management backgrounds, and some people who learned the old fashioned way, in the trenches. The hard lessons learned by the builders need to be shared with all involved in the bridge design and selection process.

I mentioned the problem of many design engineers never getting an opportunity to spend meaningful time in the field to really understand how things get built. The same is true for our educators, some never get an opportunity to learn in the field. Our collective engineering knowledge flows down from our instructors and mentors. However, rarely do we see cases where our collective building knowledge flows up to our educators. So, for educators to learn more about the challenges of building high-tech signature bridges, they should be given the opportunity to spend time in the field. Today, most knowledge flows from our engineering schools down, to the designers, and finally down to the builders. In order to build better bridges our educators must learn from the builders, so that in effect we bring the knowledge full circle.

Further, as designs and structural analysis have grown much more complex with the use of computers and software, it seems that some designers are getting further and further away from the reality of building the work. Elegant bridge designs ultimately have to be built by people, not computers, so designers should be wary of accepting what their computers spew out and ensure realism goes into their designs. Computers and software continue to rapidly advance, so grants should be provided to allow researchers, instructors, and designers to learn how to harness state-of-the-art methods to improve delivery of signature bridges.

Over the past ten years the FHWA has had an average annual budget of about $700 million for research and technology programs. This funding needs to be maintained and the FHWA should be given discretion to fund programs aimed at education. Signature bridges are a unique challenge and a comprehensive training program should be developed to educate those people involved in the selection process. This training should start at the university level. Further, the FHWA should provide research grants to our educators to spend meaningful time in the field. I know many professors that would

jump at the chance to spend a summer in the field. Our educators would then be able to not only teach theory, but also practice to our engineering students.

Learn From the Past:
As George Santayana said; "Those who cannot remember the past are condemned to repeat it." There are many lessons to be learned from those who have walked before us in the bridge industry. The 1940 collapse of the 2,800 foot main span of the first Tacoma Narrows Bridge provided lessons for future suspension bridges like the Mackinac Straits Bridge (opened in 1957) where designers paid special attention to how the main span deck would behave in the wind.

In England, the Brickton Meadows footbridge collapsed in 1967 and later in 1985, the Ynys-Y-Gwas bridge collapsed as a result of post-tensioning problems. These collapses led to a ban on the use of post-tensioned bridges in the United Kingdom in 1992. Lessons were derived from these collapses and the ban was lifted in 1996.

More recently, the Sunshine Skyway in Tampa underwent emergency repairs which have led to many positive changes in post tensioning grouting materials and construction details.

Duke University professor and renowned bridge author / historian, Henry Petroski brilliantly captures much of the important developments in the major bridge market during the past 150 years in his book "Engineers of Dreams". This book is a "must read" for all of us in the bridge industry. Professor Petroski may have said it best; "Every city has its distinctive bridges, whether they be oddly configured to satisfy local geology and politics or curiously named to commemorate engineers whose accomplishments have long been since forgotten by the users of the bridges. In any case, knowing the story of any bridge and its builders invariably reveals a rich and rewarding chapter in the history of a place, its people and their dreams."

Don't Try This At Home:
In 1961, President John F. Kennedy addressed Congress and said: "I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the moon and returning him safely to the earth." To achieve this goal, NASA, its engineers, and contractors had to design and develop many new systems and equipment. The harsh conditions of take-off, space travel, lunar landing / take-off, and eventual re-entry to earth's atmosphere led to the design of a space craft driven purely by functionality, not form. I would think that even today's politicians that grew up watching *Star Wars* still recognize that they have no place in dictating aesthetic standards for space craft.

While bridges are not rocket science, they are in fact some of the most sophisticated structures that we build on earth, and we should only allow the most knowledgeable individuals to drive our bridge selection process, not the least knowledgeable.

Owners and selection committees are sometimes swayed by style and not substance. This can lead to problems including design concepts that overrun the designer's "lump sum" design fees and concepts that overrun original construction budget estimates. Owners and selection committees should evaluate a designer's past performance and their ability to deliver efficient, economical, and maintainable designs. Owners should also use independent peer reviews by qualified designers and builders. Likewise, owners should be able to pre-qualify their contractors to ensure experienced people are assigned to the work.

The design / build contract delivery system may offer some improvement in this regard. But, it won't solve all of the problems. In 1998, the Transportation Equity Act for the 21st Century (TEA-21) became the new authorization legislation for our nation's surface transportation initiatives. Part of TEA-21, FHWA approved criteria and procedures for design-build contracting. The so-called "Design-Build Contracting: Final Rule" became effective in January 2003 and as part of TEA-21 it required a "Design-Build Effectiveness Study" which was published in January 2006.

This report contains the results of a comprehensive survey conducted in the fall of 2003 and the summer of 2004. In the report's recommendations, it pointed to the experience and expertise of transportation managers as a "key challenge". The report went on to recommend design-build training, not only for transportation managers, but also for designers, and contractors.

The report also mentions a growing trend in "best-value" criteria when selecting a design-build consortium, and recommended best-value selection, rather than low bid as a positive step in improving the design-build process. Best-value evaluations consider many concrete criteria such as project cost and duration, but also may include subjective criteria like; team reputation, project management, and quality control. And I would have to conclude after some of the recent bridge selections made in the United States in the past ten years, that if a best-value selection committee was given "aesthetics" as a criteria, they may not get "best-value" as there is nothing more subjective than aesthetics. This is especially true if you consider long-term maintenance costs in addition to the value of the design-build contract.

Designers need to provide owners with accurate budgetary numbers for proposed concepts. During construction, designers need to put aside pride of authorship and be open to minor detail changes that may enhance the safety, quality, or productivity of the field operations.

Contractors need to temper their enthusiasm for building high-tech / high-risk bridges and ensure before they bid that they have the appropriate pricing, experienced personnel, and proper equipment to do the job right.

Collectively; the job team, owner, designer, and builder need to partner together to make the project a success for all stake holders. Billington writes: "The very act of integrating a form during construction depends on the experience of local builders, not to mention any peculiarities of the climate and site. The designer must feel that he is in active partnership with the builder if he is not actually the builder himself. This feeling of partnership is more than a practical necessity; it is a central basis for the new art form. The designer in his office can sketch beautiful diagrams, make elegant calculations, and build handsome models, but all such professional work is wasted if it does not lead to a structure that can be built economically and well. This partnership extends to the public because the completed design must be needed, fit the need, and be within the means of the public. The designer works, therefore, not just for private profit but also for public welfare. As a student of the laws of nature, the engineer is society's expert; but as an observer of the patterns in society, he is its servant."

Assigning experienced people to the task and solving problems and issues early in the project is one of the best ways to improve a project's chance for success. The focus of early planning should be on a balanced, holistic approach to the design.

Constructible / Maintainable Details:
Of all of the competing criteria (load capacity, span lengths, seismic criteria, etc.) constructability is the one criteria that has notably suffered in the modern signature bridge era. Designs that dictate high-density reinforcing steel and post-tensioning inevitably cause major difficulties with the constructability. There can also be problems with the owner's erection sequence that can impact constructability.

Jeffery Gorb, a principle architect at Vollmer Associates in New York City has spoken about restoring aesthetics as design priority in bridge design. In my view, in the signature bridge market, aesthetics is already the priority. However, in what he refers to as the; "The Four "C's" of Bridge Aesthetics" he says designs should consider; the *CONTEXT* in which the bridge is located, the *COMPREHESIVENESS* of design by taking aesthetics into account from the start, the *COST* of the design, and finally the C*ONSTRUCTABILITY* of the design.

Designs should consider the capabilities of the contractors, their people, and their equipment. One-of-a-kind unique structures often dictate expensive one-job-use specialty equipment which drive up the bridges cost. For example, some of the increase in cost on the SFOBB Skyway was a result of the many one-of-a-kind pieces of equipment which had to be designed and manufactured to cast and install the largest precast segments in the world which weighed up to 800 tons.

Designs should also consider the journeyman craftsman and his abilities. More and more, we are seeing details and construction requirements where tolerances are becoming extremely tight. For example, many congested zones of rebar and PT must be now be fabricated and installed to extraordinary tolerances, and precision costs more money. We are also seeing welding details and inspections that rival those of the nuclear industry.

Certainly there is need for continual innovation in the bridge market, with new designs, details, materials, erection methods, and so on. But, before specifying unproven technology or materials into a bridge, a risk assessment should be done; asking simply, "what if this doesn't work?".

We can't afford for all bridges to be "Eiffel Towers". We know what a steel girder or AASHTO girder bridge can do and how long they will last, and we need to now explore making the most of new materials like high performance steels, fiber reinforced polymers, and high performance concrete structures which have great promise for lower initial costs and longer service life.

For the sake of the bridge community today we need to put some more practicality back into the bridge designs. For the sake of society tomorrow, we need to ensure the bridges we are building will in fact stand the test of time, and perhaps even exceed expectations. What is better, an awe-inspiring bridge that needs to be prematurely replaced, or a robust, yet attractive bridge that goes well beyond its design life?

Don't Be Fooled by good Looks: To be sure, all new bridges are designed to meet minimum design criteria such as AASHTO. However, it seems that many recent signature bridge designs are being evaluated primarily on aesthetics, assuming that all of the other functional selection criteria are taken care of. Competing designers focus on aesthetics, and now put forth design concepts geared towards delivering the highest "wow factor". A quick visit to any of the major bridge initiative web sites for will give you an idea of direction we are headed in the signature bridge market. I look in awe and admiration at some of these concepts; but as a builder, question the structure's overall value and wonder if its elegance will stand the test of time.

We should all ask the question; what good is a bridge if its ultimate design was primarily dictated by form and aesthetics, but it won't achieve its design service life? Admittedly, many of us won't be around to know if a bridge achieves its service life. However, we should heed early warnings from aesthetically driven bridges.

Case in point, the Sunshine Skyway Completed in 1987 at a cost of $245 million, was hailed as a landmark by the American Society of Civil Engineers for its aesthetics, low cost, and minimum maintenance.

"This bridge design elevated the functionality of engineering to a true art form."

Yet; less than twenty years later according to local press, thousands of Tampa Bay area motorists cursed the bridge and its designers as emergency repairs caused hours-long traffic jams for days. In the future; to maintain the structural integrity of the Skyway, it has been estimated that millions will have to be spent for necessary repairs. Much of the bad press Tampa Bay's Skyway has received is probably unwarranted, as its design and construction were hastened when a ship collided with the existing bridge in 1980. Accordingly, it was known to be a bridge pushing the limitations of the industry at the time.

To the credit of the Florida DOT, it has aggressively sought to inspect and repair not only the Sunshine Skyway, but also other post-tensioned bridges in Florida, and their findings and lessons learned now influence much of the recent design details and practices used on post-tensioning and grouting details throughout the United States.

In Dallas the first of three Calatrava bridge designs is underway as part of the Trinity River improvements. I will certainly monitor the progress of this program with interest.

To counter the trend of inefficient structures, we should look hard at accepting aesthetically forced shapes, such as leaning pylons and unnaturally curved structures.

Maintain What We Build:
Completed in 1928, and spanning over the Ohio River between West Virginia and Ohio, the Silver Bridge collapsed in 1967, and resulted in 46 deaths. In the aftermath, Congress conducted hearings and established a law that established uniform standards for inspecting bridges. In 1971, the first National Bridge Inspection Standards (NBIS) were issued to satisfy the mandate of Congress. And, as a result of this law, today we have the National Bridge Inventory (NBI) which is substantially complete for all public road bridges.

Due in part to this law and excellent stewardship by our departments of transportation and bridge authorities, there are today many shining examples of bridges going beyond their originally intended design life, carrying multiples more traffic than ever intended, and still proudly dominating their skyline.

Sadly, some bridges prematurely succumb to the ravages of time, and therefore do not reach their design life. The Mianus River Bridge in Greenwich, Connecticut collapsed in June 1983 as a result of excessive corrosion in a hanger pin connection. Unfortunately, for bridge lovers, Conde MuCullough's Alsea River Bridge in Oregon was replaced in 1991. And in Maine, David Steinman's Waldo-Hancock Bridge was recently replaced after succumbing to an inadequate maintenance program.

Although the National Transportation Safety Board has not issued their findings on the cause of the August 1, 2007 collapse of the I-35W bridge in Minneapolis, inspection and maintenance of the bridge have been brought into question.

There are almost six hundred thousand bridges in the United States. A year 2000 FHWA study concluded that about 28% of the total deck area on these were defective. Later, a 2003 FHWA study concluded that nearly 160,000 bridges were substandard. These and other studies should be enough of a wake-up call that we need to aggressively maintain our bridges, as we will need to spend huge monies on repairs, retrofits, and replacements in the future. So, before we start spending disproportionately huge sums of bridge dollars on aesthetics, let's look at the big picture and ensure we can take care of what we have.

FHWA recognized the need to manage our aging bridge infrastructure and in 2003 initiated its "Bridges for the 21st Century" program whose aim is to develop cutting-edge solutions to the problems of the nation's aging and deteriorating bridges.

Also, the Turner-Fairbank Highway Research Center (TFHRC) in McLean, Virginia is home to the FHWA's Long-Term Bridge Performance Program (LTBP). The LTBP program is an ambitious 20-year research effort that includes detailed inspection, periodic testing, continuous monitoring, and forensic investigation on various bridges throughout the United States. The intent of the program is to impact the value, success, and efficiency of bridge management systems in the future.

Because it is irresponsible to build magnificent bridges that prematurely fail, service life and maintainability must be emphasized during the design stage of a bridge. To do this we have to make sure that our designers are being informed of best practice methods from the field and that on-going research is being evaluated and implemented as appropriate into our designs.

Is the Pendulum Swinging Back?

There have been some recent indications that we are learning to not be seduced solely by good looks and charm. Delaware's new Indian River Inlet bridge was completely designed and ready to be bid. The problem was, no one came to the dance (would bid the work). So, after the Delaware DOT and the selection committee spent years sweating out the details, and spending millions in design fees, the final design was scrapped. After living through this process, one official at the Delaware DOT told me he'd concluded that "Signature bridges are not good stewardship of public money." Unfortunately, Delaware is still without a new bridge at the Indian River Inlet.

Recently in Omaha, Nebraska, a radical pedestrian bridge over the Missouri River met a similar fate when bids came in twice the budget and again a final design was thrown away. It too also, went design-build.

Last year I sat on a panel of judges who evaluated conceptual bridge designs developed by high school students that could have been built to replace the east span of the San Francisco Oakland Bay Bridge. I was impressed with all of the concepts. They had to consider many real world variables like site conditions, span lengths, vertical clearance, seismic criteria, and aesthetics. I was especially impressed that the competitors were also evaluated on life-cycle costs. The high school students unveiled several unique designs that day, including a DNA molecule shaped superstructure; far-fetched in some ways, but on par with many designs touted by some bridge architects recently. To be sure, this contest was grossly simplified. Yet, all of the teams addressed how long their structures would last and equally important, how they would pay for their bridges.

I am hopeful that some of these recent events point to some common sense coming back into the signature bridge selection process. Yet, as I talk to many bridge people and read press releases for signature bridge initiatives I continue to sense a lot of frustration with the process. So, I would have to conclude we have much to learn about building better bridges.

Building Better Bridges:
If we are to speed delivery and build better signature bridges, the politics of the process has to be minimized. Society needs allow the process to be driven by the most knowledgeable owners, designers, and builders. Overall bridge value should drive the selection process; not aesthetics, if we are to protect future generations from a disproportionately high bridge infrastructure expense.

So, as bridge people, we are rightly proud of our collective accomplishments and contribution to society. Moving forward, it should be our collective goal, to dream, design, and build the best bridges we can, properly balancing form and function.

To paraphrase President Kennedy, I believe that this nation should commit itself to achieving the goal, before this decade is out, of addressing this issue and finding a way to build better bridges.