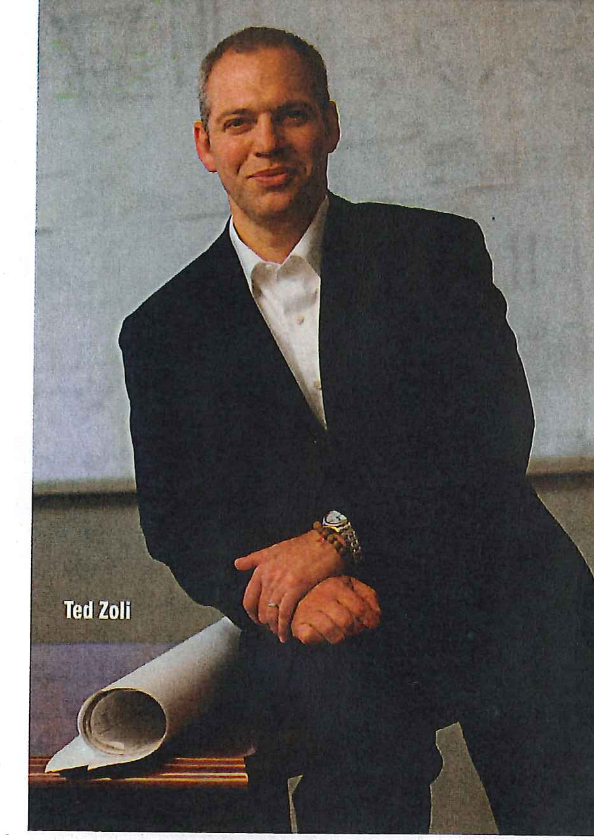
Editor's Note



Ted Zoli

COMMUNITY outreach was an important component of two of the projects featured in this issue—the Brightwater Treatment System, in King County, Washington, and the Lake Champlain Bridge replacement, which links the communities of Crown Point, New York, and Chimney Point, Vermont.

In the case of the Lake Champlain Bridge, the daily lives of residents were severely disrupted by the closure of the structurally distressed 80-year-old bridge, as they were cut off from employment, medical services, and child care, for example, and local farmers faced the problems of not being able to bring in their fall harvests or tend to their livestock. The public outcry was extraordinary, and as a temporary solution a ferry service was implemented.

As Theodore P. "Ted" Zoli, P.E., M.ASCE, explains in his first person article, the ensuing bridge replacement involved an approach known as dynamic design/bid/build, which was executed at unprecedented speed. During a six-day public involvement process residents, a public advisory committee, and historic preservation consultants were able to review five proposed bridge replacement alternatives. As a result, residents were fully on board with the design of the replacement bridge, which had been designed within a span of just 10 weeks.

In the case of the Brightwater Treatment System—one of the most advanced in the United States—King County established a comprehensive public outreach program to alleviate any concerns and ensure that the 114-acre site would be an asset to the community. Thanks to community involvement, the facility features public open space that integrates wildlife habitats, storm-water management, and recreational and educational facilities of which the community is proud.

From the outset of the project local residents placed high importance on environmental stewardship and placed an emphasis on state-of-the-art technology that would protect water quality. To this end, King County elected to use membrane bioreactor technology in lieu of a conventional activated sludge approach.

In the current economic climate, with widespread concern over budget deficits and public spending at all levels of government, it is likely to become increasingly important to engage communities in this way. Large infrastructure projects are often costly, time consuming, and inconvenient, and they leave communities with facilities regarded as either assets or liabilities. By engaging all interested parties in decisions about location, design, timing, and cost, engineering firms and their partners can engender the type of support from those constituents that makes executing those projects easier and leaves communities with infrastructure for which they truly feel a commitment to preserving and maintaining in the future.

Brightwater Treatment System

BRUCE KATZ, *TOP;* BENJAMIN BENSCHNEIDER, *BOTTOM*

Anne Elizabeth Powell

ANNE ELIZABETH POWELL
Editor in Chief

A Bridge by the People, for the People

Familiar with the Lake Champlain Bridge since childhood, Theodore P. "Ted" Zoli, P.E., M.ASCE, never dreamed he would one day contact the New York State Department of Transportation and recommend demolition of the iconic structure.

PORTRAIT BY BRUCE KATZ

Motivated to reconnect two communities devastated by the closure of the Lake Champlain Bridge, HNTB Corporation designed a replacement span within 10 weeks. The modified network tied-arch bridge, created for maximum constructability, features a center arch span that was built off-site, floated in, and lifted 75 ft into place. The new structure opened a little more than two years after the existing bridge had been closed, setting a precedent for accelerated bridge delivery.

By Theodore P. "Ted" Zoli, P.E., M.ASCE

RESTING STATELY AND QUIETLY amid the Adirondack Mountains, the Lake Champlain Bridge made it possible for the rural bistate communities of Crown Point, New York, and Chimney Point, Vermont, to share life-sustaining economies and life-saving emergency services, including a hospital and a fire department. Nearly 3,500 motorists a day relied on the bridge as the most efficient route to work, school—even the grocery store.

I know all of this because I was born 30 mi to the east of the bridge and grew up in the region. My grandfather was a road builder, and he and my father's construction company built a few sections of the Northway (Interstate 87) through Adirondack Park. I grew up around construction equipment and could run a bulldozer long before I had a driver's license. Whenever I had a reason to go to Vermont, I would make a point of using the old bridge. The trip would cost me an extra half an hour, but the vantage point to views of the lake that you got and the whole experience of crossing the bridge made it well worth the extra time.

Little did I know while crossing the bridge that some 30 years later I would have to make a call to the New York State Department of Transportation (NYSDOT) and recommend that this iconic structure be demolished. In its place, we would design an emergency replacement span that would be the most challenging bridge of my career. The highlights:

- Health monitoring would play a key role in assessing the bridge's safety.
- We would design a replacement span in 10 weeks with an unprecedented level of public input.
- It would be the most environmentally constrained site of any project on which I have ever been involved.
- The unusually beautiful setting and the beauty of the old bridge presented a particular challenge of form and scale.
- The center arch span would be constructed simultaneously with the approach spans and then be floated in, lifted 75 ft, and attached.
- The entire environmental, design, and construction process would be completed in a little more than two years.

The Lake Champlain Bridge was a historic steel truss bridge stretching 2,187 ft across the water. When it opened, in 1929, it held an important place in the evolution of continuous trusses and in the practice of U.S. bridge engineering. Its designer, Charles M. Spofford, was an early pioneer in design methods for continuous systems, particularly trusses. His 1937 book, *Theory of Continuous Structures and Arches*, discussed in detail the design aspects of continuous truss bridges. This structural form was a clear early innovation in the design of continuous trusses, and Spofford's role in its development cannot be overlooked.

By 2009 the bridge had reached 80 years of service life, and deterioration was progressing rapidly in both the superstructure and the substructure. That summer the bridge's joint owners, New York and Vermont, executed a bistate agreement to commence project scoping. Under this agreement, NYSDOT would be responsible for advancing the project. The three colead agencies—NYSDOT, the Vermont Agency of Transportation (VTrans), and the Federal Highway Administration (FHWA)—would share project oversight.

FOR MANY AREA RESIDENTS, OCTOBER 16, 2009, BEGAN AS ANY OTHER DAY: WITH A COMMUTE ACROSS THE LAKE CHAMPLAIN BRIDGE. THEY WOULD BE THE LAST EVER TO USE THE ICONIC SPAN.

HNTB Corporation, out of our New York City office, with a team of subconsultants, was contracted to carry out project scoping with the intent of continuing through the environmental impact study and possibly through bridge rehabilitation or bridge replacement. Project scoping through final design was estimated to take approximately five years. In a matter of weeks, this timeline would change dramatically.

ON AUGUST 26, 2009, representatives of the colead agencies and HNTB walked the bridge. There were a few dozen of us. The truss was clearly under distress, but I had seen worse. After the walk-through, we got in a boat with NYSDOT's Region 1 structures engineer, Tom Hoffman, to inspect the unreinforced piers, which were in surprisingly bad condition. I leaned over to Tom and said, "We won't be replacing this bridge because of the truss. It's hurt but looks repairable; the piers look [shot]."

The new Lake Champlain Bridge, viewed from the New York side, opened to traffic on November 7, 2011.

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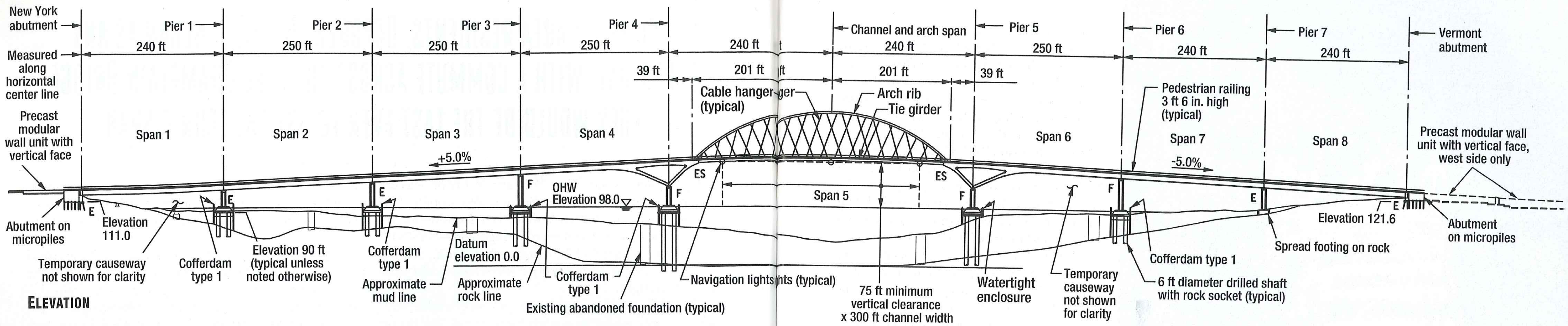
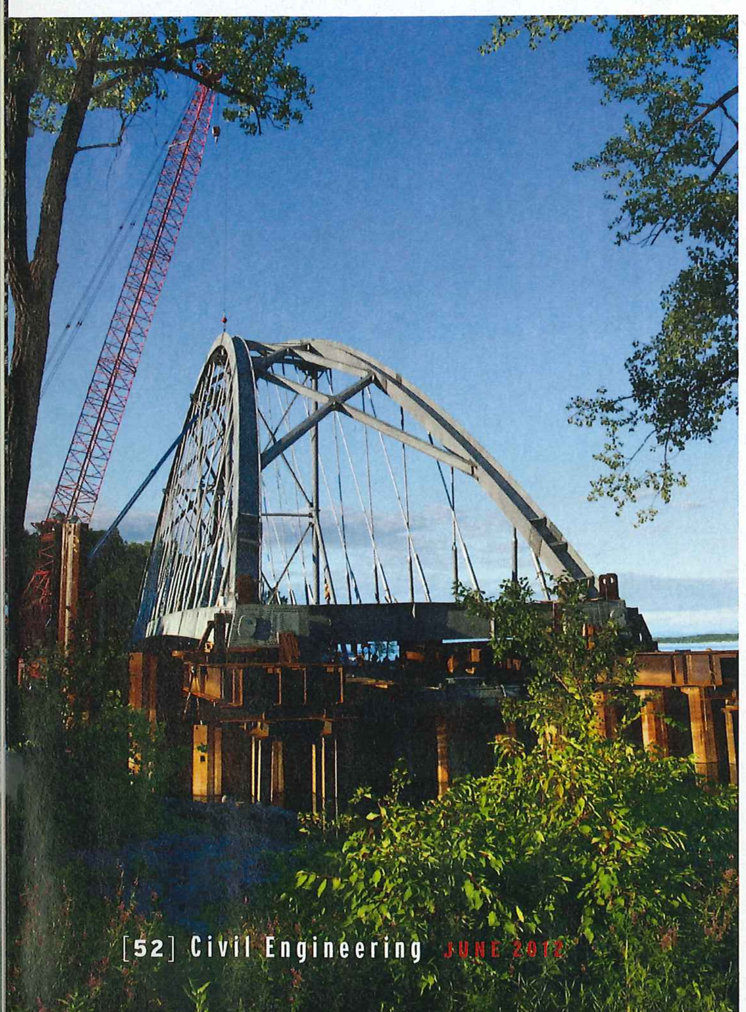


ELEVATION

About two weeks after that boat ride—and typical of early fall in upstate New York—the lake had dropped to its lowest annual level. Tom had the presence of mind to go out and look at the piers again. The newly exposed areas were worse than expected. He ordered concrete cores to assess the concrete's strength and behavior. They came back: the outside 18 in. of the pier concrete was basically rubble.

While NYSDOT was testing the cores, we performed a complete evaluation of the piers. Of major concern was significant cracking and freeze-thaw induced damage, both at the bearing seats and at the waterline.



Assessing the condition of the Lake Champlain Bridge was the first time we deployed accelerometers and tiltmeters to identify a structure's behavior and fragility. This provided NYSDOT with continuous measurements of the piers under daily thermal cycles. A visual inspection told us the piers were damaged significantly and quite fragile, but there is nothing like quantitative evidence to put more certainty behind a tough decision like closing a bridge.

In the literature regarding the design of the Lake Champlain Bridge, Spofford was asked specifically about the use of unreinforced piers, but he doesn't give a direct answer. He must have been influenced by the quality and strength of the concrete, which he had developed specifically for the project. Next to the site were iron ore mine tailings, which were used as aggregate for test batches of concrete. The iron ore mines on the New York side of Lake Champlain were prolific, and the iron ore quality was the highest from anywhere in the world at the time.

Spofford conducted tests at the Massachusetts Institute of Technology using the mine tailings as aggregate and declared the concrete to be unusually strong. As part of the test series, he even simulated casting concrete in deep water (more than 50 ft) and invented a new means of placing underwater concrete by bucket instead of by tremie. However, this method of construction precluded the placement of reinforcement without divers, and using divers would have been unusually complex, expensive, and dangerous.

FOR MANY AREA RESIDENTS October 16, 2009, began as any other day: with a commute across the Lake Champlain Bridge. They would be the last ever to use the iconic span.

Our inspection and the subsequent structural evaluation for overall safety were causing us real concern. I called NYSDOT's chief engineer, George A. Christian, P.E., at 10:30 AM. I remember it clearly. We told George our work to date had demonstrated the need to close the bridge until further work could demonstrate its safety. I had mixed feelings about our recommendation. As an engineer, I believe a large part of my job is to do everything I can to extend the life of such an important bridge—similar to an M.D.'s pledge to first do no harm. But the piers' deterioration represented a significant threat to public safety. I couldn't rule out the potential of a localized pier failure that would cause a catastrophic structural collapse. I did not believe the bridge was in imminent danger of failure, but I could not argue for its safety. Looking back with the benefit of hindsight, I feel that lake ice caused the pier damage and would have further jeopardized the safety of the bridge for the coming winter.

On August 25, 2011, the assembled center arch span awaits flotation to the lift location.

George made the decision alone, and he made it swiftly. By 1:30 PM the bridge was closed.

We immediately began working on an emergency stabilization strategy. But after three weeks of developing a workable solution, we came to the conclusion that we would spend more money fixing the bridge than we would replacing it. Further, to perform repairs, crews would have to underpin the structure, and such operations, coupled with high winds, cold weather, and lake ice, could further destabilize the structure. The risk to personnel was too great. On our recommendation, the bridge was destroyed by means

The center arch span is lifted into position on August 26, 2011.

HNTB, TOP; © TREY CAMBERN, BOTTOM LEFT AND OPPOSITE

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In this view from the New York approach, the span lift makes its vertical journey to fit into place.

of controlled demolition on December 28, 2009.

The immediate effect of the bridge's closure on local residents was far reaching. The only viable alternative route during winter months added 85 mi to commutes. Residents were cut off from employment, medical services, child care, and family members. Farmers with fields on opposite sides of the lake could not bring in their fall harvest as there was no way to get equipment across the lake. Others were leaving home at 3 AM to arrive at work on time. The public outcry was on a scale that is hard to articulate. Their lives simply did not work with the bridge out of service.

On October 20, 2009, less than a week after the closing, Vermont's secretary of transportation, David Dill, issued a declaration of emergency, followed the next day by New York Governor David A. Paterson's state disaster emergency declaration.

The colead agencies had considered building a temporary bridge but rejected the idea due to the high cost and the time to construct (at least six months). As short-term mitigation, NYSDOT and VTrans negotiated subsidies for two existing ferry services, which allowed commuters to cross the lake at no cost. In addition, several shuttle bus services, with corresponding park-and-ride areas, were created on each side of the lake.

Our subconsultant, MJ Engineering and Land Surveying, P.C., of Clifton Park, New York, had been involved in designing other ferry terminals on Champlain and began building a third emergency ferry terminal to reestablish traffic at the bridge site. Under enormous pressure, MJ began design of the temporary ferry service on November 1, 2009. It opened on February 1, 2010—an amazing feat and welcome relief, which ended the states of emergency.

To expedite development and delivery of the new bridge, NYSDOT decided to complete design on a compressed schedule with the traditional linear functions of final design/bid packaging, advertisement, and permitting performed concurrently. We have since termed this approach dynamic design/bid/build, and the project was executed at an unprecedented speed, shaving years off conventional design processes. It would be the fastest, most under-the-gun job of my career.

We introduced five proposed bridge replacement alternatives during a rigorous six-day public involvement process, which began on December 10, 2009. During those six days, we met with the historic preservation consulting parties, a public advisory committee (PAC), and the public at large.

The first in the series of meetings was attended by the colead agencies, historic preservation consulting parties, and our design team. We were able to explain the risks and drawbacks of replacing the bridge with another truss bridge, as well as discuss the potential benefits of using a more modern bridge type. Our goal was to collect input and alleviate possible issues that could arise during the 30-day review process required by section 106 of the National Historic Preservation Act of 1966, which began with this meeting.

The following day, December 11, 2009, members of the FHWA, NYSDOT, VTrans, and our team met with the PAC to reveal the proposed replacement alternatives. The PAC showed overwhelming support for the network tied-arch bridge, but many felt the bridge lacked something—the transition from arch span to standard steel girders was too abrupt.

Scott Newman, the historic preservation officer for VTrans, suggested extending the arch design below the bridge deck to better reflect the design of its historic predecessor. His sensibility informed a new design concept, a network tied-arch main span supported by multigirder rigid frames that could be well integrated into the construction of the crossing.

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The new design, which I call a "modified" network tied arch, was unveiled on December 12, 2009, during three back-to-back public information meetings in Ticonderoga, New York. The sessions drew more than 600 attendees. Residents voted overwhelmingly for the modified network tied arch.

On December 15, 2009, the PAC reconvened to make a formal recommendation of the modified network tied-arch alternative to the commissioner of NYSDOT and the secretary of VTrans. Within just two months, public anger over closing the bridge had transitioned to a deep appreciation of our work for a replacement. I have been to many public meetings on a wide array of projects. For a public whose lives had been so disrupted by our closing the old bridge to show us such appreciation for the new design was the most humbling experience of my career. I cannot overstate the effect that this had on the design team. Of course we had many late nights and lost weekends, but knowing the public was in great need and was so appreciative of our work made long hours pass quickly.

THE NATIONAL ENVIRONMENTAL Policy Act (NEPA) process for the new bridge began on December 1, 2009. The colead agencies resolved to reduce the minimum five-year process to four months without taking shortcuts. This was an extremely ambitious goal given that we were rebuilding a bridge in a location we would never have built in otherwise due to the significant environmental constraints. Three major decisions expedited the NEPA process:

- The replacement structure would be constructed along the same alignment as the original bridge.
- NYSDOT would manage the demolition, new bridge design, and temporary ferry construction separately to eliminate confusion.
- To expedite the extensive permitting process while still following FHWA and NYSDOT guidelines, the FHWA arranged a federal regulatory agency summit on January 12, 2010. Federal agencies that would have a role in the project participated, and all agreed on the permitting requirements, process, and project time line.

Collaboration among the more than 40 agencies continued throughout the permitting phase, including approvals needed from the U.S. Coast Guard, the U.S. Army Corps of Engineers, endangered species consultants, and various agencies for Clean Water Act provisions, as well as coordination with the Saint Regis Mohawk Tribe.

Infrastructure has some similarities to our health care system. As a culture, we tend to be very good at "trauma" and not so focused on maintenance. Typically, a bridge like this has a yearlong design period. However, given the economic hardships of the bridge outage and the cost of the temporary ferry system to both states—$30,000 a day—our team of 30 engineers delivered the final design in 10 weeks.

Preliminary engineering began on December 16, 2009, following the public involvement process. We worked closely with NYSDOT, VTrans, and the FHWA and held early technical coordination meetings. We presented the overall design concept to the colead agencies on January 6, 2010. Our preliminary drawings included proposed geometry, typical bridge sections, and conceptual details for primary structural members. During the meeting we established the necessary design criteria and the roadway cross section and identified the new structure's functional needs. There was no room in the schedule for changing direction or modifying the basic design concepts once final design began. Engaging all involved agencies was critical in making conceptual design decisions.

The mandatory 30-day review period required by section 106 of the National Historic Preservation Act ended on January 14, 2010. That

On August 26, 2011, workers unfurled the United States flag on the center arch span prior to the start of the span's journey across Lake Champlain.

same day, New York and Vermont announced that the modified network tied-arch bridge concept would be advanced into final design. The new bridge preliminary design and NEPA process were approved by the FHWA on February 5, 2010.

The new Lake Champlain Bridge would be composed of eight spans with one network tied-arch signature span. Total bridge length was set at 2,200 ft with seven approach spans measuring up to 250 ft and a 402 ft long network tied-arch signature span.

The bridge design met three major criteria:

• Constructability: Accelerating construction was the driving factor behind our design. To deliver value to taxpayers, I believe a designer needs to focus on the way the bridge is fabricated, built, and transported to its site. Optimizing the amount of materials made sense a 100 years ago, when materials represented a significant portion of the overall cost of the bridge. Today, I would argue labor is the most significant cost in bridge construction. Material efficiency is not irrelevant, particularly as spans get longer and bridges get heavier, but focusing on how a bridge is fabricated, transported, and erected is enormously important and informs my work as a designer. When you have integrated construction into every aspect of design—even the form of the bridge—cost-effectiveness is a direct output.

• Safety: The Lake Champlain Bridge is also an example of exploring safer structural systems. Using crossed instead of vertical cables for the arch results in an entirely different structural behavior, making the overall system much more tolerant to damage in that one or multiple cables can be damaged or lost without impacting the safety of the system. The more common arrangement—arches with vertical hangers—particularly slender tied arches—are not nearly as damage tolerant. I would argue that network arches should be the standard and that only in limited circumstances should tied arches with vertical hangers be adopted.

In addition, we made a concerted effort to eliminate fracture-critical elements entirely from the project. To this end, the arch is supported by a highly unusual multigirder delta frame. The bridge can tolerate the loss of any one of the girders. A similar design strategy was adopted for the floor beams and the tie girders such that they are not fracture critical.

• Austerity: Our work, at its best, is informed by the idea that bridges are paid for with other people's money, and that demands a certain sense of austerity and value. We had an obligation not only to put the bridge back as quickly as possible but also to design a structure that would be cost effective yet would deliver on the opportunity that such a beautiful setting and the replacement of such an important bridge require. There are no aspects of the Lake Champlain Bridge designed purely for aesthetics. There is a notion within the bridge design community that aesthetic bridges must be enormously challenging to build. That notion is silly to me and disrespectful to the people who have to fabricate and erect a structure. This sort of approach ultimately yields a very expensive project, one of questionable value. To me, a good bridge should do exactly what it is designed to do; it should be a practical part of the environment and somehow more transparent for it.

Our goal was to deliver to potential contractors as much information as possible as early as possible. This allowed contractors to understand the type of construction and to begin identifying subcontractors. It also gave them more time to plan site access and construction sequencing, given the environmental and historical sensitivities.

In an unprecedented move, the colead agencies agreed to make the 75 percent contract documents available online to interested contractors by March 1, 2010—two and one-half weeks before official advertisement of 75 percent plans, March 17, 2010.

A prebid meeting, with 95 percent contract plans and specifications in hand, was held on March 29, 2010, to provide additional information to interested contractors. The major addendum was a full swap-out of the 432-sheet plan set. Details not critical to bid, including camber and haunch tables, bar lists, and load rating tables, would be delivered to the winning contractor at contract award. The proposed schedule, although expedited, still followed required time regulations per NYSDOT's standard bid process and maximized the amount of time that contractors had to prepare their bids.

> INFRASTRUCTURE HAS SOME SIMILARITIES TO OUR HEALTH CARE SYSTEM. AS A CULTURE, WE TEND TO BE VERY GOOD AT "TRAUMA" AND NOT SO FOCUSED ON MAINTENANCE.

To meet the aggressive design schedule, we decided early on in the design process that full 3-D finite-element models of the bridge (arch and approaches in their entirety) were necessary. For drawing production, we developed integrated 3-D computer-aided design (CAD) models in parallel. In the case of an emergency project there is little time for the design process's typical mistake-and-correction cycle. The best approach in situations such as this is to draw and model the bridge in 3-D because it provides more answers than questions and, more often than not, saves time and money.

Eight bids were received and publicly opened on April 15, 2010, six months after NYSDOT had closed the bridge and three months after final design began. Flatiron Construction Corporation, of Firestone, Colorado, the low bidder, came in at \$69.6 million, 2 percent under the engineer's estimate.

All permits required for the new bridge were in place before the contract was awarded on May 27, 2010. Both governors attended the ground-breaking ceremony on June 11, 2010.

The eight-story-tall, 402 ft center arch span was fabricated off-site, floated 2 mi in, lifted 75 ft, and installed on August 26, 2011. The preassemble-and-lift scheme allowed the contractor to construct the center arch span and approach spans simultaneously, reducing the overall construction schedule.

The heavy lift offered other advantages:

• Building the center span was easier on the ground than over water.

• The modified design's delta frame provided more clearance, making it easier to lift and fit than the originally proposed conventional network tied-arch design.

• Once the arch was in position, precast deck panels were used instead of traditional cast-in-place construction. This eliminated the need for the extensive formwork and cold-weather concreting.

• Both the heavy lift operation and the precast-concrete deck required little to no interruption in the navigation channel.

Arch stability is a crucial part of the erection sequence, not just during float in and heavy lift operations but also during concrete panel installation, where the arch sees more deformation than at any other time and the stability of the arch is most compromised.

Erdman Anthony, based in Rochester, New York, served as Flatiron's erection engineer for all construction activities, and contractor and erection engineer worked together flawlessly to ensure a safe and expedited erection.

When the arch span arrived at the bridge site later that morning, Flatiron began lifting operations, with strand jacks supported at each corner of the delta frames. Crews began the heavy-lift work of hoisting the 1,800 ton arch into place, chipping away at the 75 ft journey in 18 in. increments. With Hurricane Irene approaching in less than two days, these were nervous moments to ensure that the arch reached its final destination with adequate time to make the necessary connections for interim stability. Flatiron and Erdman Anthony did a wonderful job under a good deal of pressure and with hundreds of onlookers at either bank.

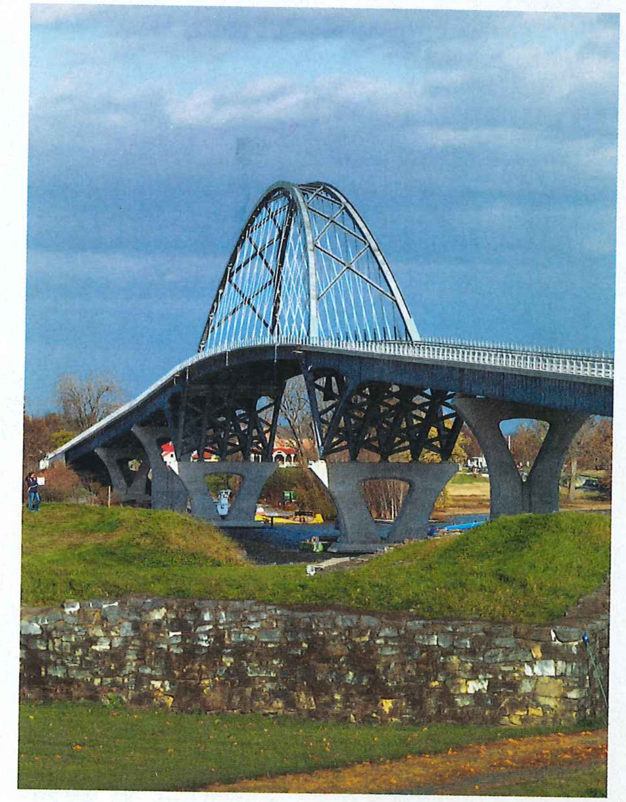
We were on-site to facilitate coordination and communication between NYSDOT's engineer in charge, the contractor, and the design team. Being on-site and accessible during construction meant we could answer questions on the fly and address problems immediately or proactively avoid them.

The fit-up of arch span to approach spans took place late that night as crews bolted the crossbeams into place. By the end of the following day, August 27, 2011, the bridge steel was essentially complete.

Given the complexity of the structure and tight tolerances and short schedule, there were concerns about fit-up during construction. However, all went remarkably smoothly, a testament to the fabrication prowess of High Steel Structure, Inc. Within a few days, arch erection at the Port Henry site began, Flatiron requested daily steel shipments to keep up with erection activities.

The new bridge opened to traffic on November 7, 2011, nearly two years after the original bridge had been closed. A grand reopening celebration was held last month.

My hope for the new bridge is that it serves the public well for many years and that it lives up to the opportunity that such a beautiful setting and the replacement of such an iconic and important bridge deserve. Bridge making is a culmination of a great communal effort from owners, engineers, and builders to achieve something important. It has been an honor to be a part of the creative effort of such a large and talented group of people—and to serve the public. In this sense, I think of bridge making as craft, distinct from what some have termed structural art. I am taken by Yanagi Sōetsu's sensibility about fine art as "for the few, by the few" and craft as "for the many, by the many." In this sense, bridge-making is decidedly craft. **CE**



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Zoli says of the completed bridge, "I am proud of having been associated with something bigger than me and the grand feeling about what we can do when we work together."

Theodore P. "Ted" Zoli, P.E. M.ASCE, the recipient of a MacArthur Foundation fellowship in 2009 and of Engineering News-Record*'s 2012 Award of Excellence, is the national bridge chief engineer for HNTB Corporation, of New York City.*

PROJECT CREDITS Owner: New York State Department of Transportation and Vermont Agency of Transportation **Structural engineer:** HNTB Corporation, New York City **Construction firm:** Flatiron Construction Corporation, Firestone, Colorado **Geotechnical engineer:** HNTB Corporation, Wayne, New Jersey **Construction manager:** Region 1, New York State Department of Transportation **Approach design work:** Clough Harbour & Associates, LLP, Albany, New York **Public involvement coordinator:** Fitzgerald & Halliday, Inc., Hartford, Connecticut **Erection subcontractor:** Erdman Anthony, Rochester, New York