Theodore "Ted" Zoli, III
Chief Engineer for HNTB, Designer of 2011 Lake Champlain Bridge
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"This area, the Adirondacks, particularly mean a lot to me. I was born in Schroon Lake. My Grandfather was a road builder and was building the stretch of the Northway and my Father was running that job in Schroon Lake, which was essentially fifteen miles to the west. That Northway really changed the region in a lot of ways but I really grew up on a road job. We lived in a trailer on a road job for the first three years of my life and moved to Glens Falls. I worked construction growing up, sand and stone plants, ready mix concrete. So I really have a background in construction and that's probably why I became a Civil Engineer, a Structural Engineer. I suppose that sort of work was in my bones. But the region I would say is more so. The Adirondacks I think are an incredibly special place. Lake Champlain, we boated on Lake Champlain and Lake George growing up. I mean this is, I would say in terms of the region, these are really important features but also it's an absolutely gorgeous place. And also the bridge site, I think if you just look around you, the bridge site is absolutely gorgeous, the mountains behind us; it's an incredible place.

Bridge a touchstone

Crossing the Crown Point Bridge when I was a kid - I used to date a girl in Vermont and so it was actually the most direct way from Glens Falls to where she lived, just north of St. Johnsbury. I used to cross the Crown Point Bridge. The bridge, in a way, it's not exactly on the way to anywhere in terms of interstates. You really have to want to be not on an interstate and it, in a way. it's something quite different than I think nowadays. We tend to just drive the fastest route and not drive for the sake of driving. I think it's really different than maybe the '30's or '40's when going out in your car for a drive is actually something you would do as , let's say, as recreation. I don't think that happens anymore at all. But in saying that, there couldn't be a better way, a more beautiful stretch of road, from driving through the Adirondacks, crossing the Crown Point Bridge over the mountains to the east side of Vermont. I mean just, there's not a stretch of it that isn't gorgeous the whole way.

I would say that bridges for me growing up always had a certain sort of appeal and the Crown Point Bridge being so dramatic. I mean really essentially you are in the mountains; you get to the Champlain Valley so you have a little bit of a perspective. You have some horizon and there the bridge is rising above the lake. It's hard not to have an image of the bridge in your mind having crossed it just once. But it's something that it was really the marker between Vermont and New York. And it was, maybe it wasn't quite the halfway point, but it was the third point on my trip. So it was always, there's something about it that the Crown Point Bridge was a touchstone I would say.

Significant public works project

But in terms of the bridge as a piece of engineering, there's something remarkable about it. The old bridge had to just get enough navigational clearance. It really rises quite quickly. It's visible from the shoreline and, having boated on Lake Champlain but also the way the shoreline undulates in Lake Champlain, you can see the bridge in pure elevation from a couple of different vantage points. It's really unusual for a bridge. Usually bridges you don't see in pure elevation unless you're in a boat. This is a bridge that you can see in pure elevation right from the shoreline. In fact, looking back behind us you can see the bridge in pure elevation right from Port Henry and the same from the Vermont side. So it's really special in terms of that sense of its setting.

As a piece of structural engineering, for me the beauty of bridges and truss bridges like the Crown Point Bridge are good examples, is its pure structure. There's no, there's nothing else about it other than structure and so the form, the shape of the structure is something that comes from the mind of an engineer. I think in that sense it's a compelling, let's say, opportunity to practice because your sense of design is really directly replicated in a structural form whereas in a building the facade so covers it so you don't see the structure quite so much.

Well, you know I would say any bridge, any significant public works project, changes the way the world works and regions function and so particularly a bridge over Lake Champlain. You know it's a 130 mile lake and there's not a lot of ways to cross, especially in the wintertime - no ferries in terms of their reliability. But also just connecting the regions, I imagine that it was the biggest event in this region probably in the last century as a piece of public works. And that's not I would say unusual. Bridges especially in the era of great bridge building, which was in the '30's, the '20's and the '30's, many such bridges were built. And I think it really ushered in economic prosperity, not just in this region, but throughout the Northeast, and changed the way we think about, let's say, modernity and how to get from one place to another.

I would say it's hard to imagine a more significant event in terms of public works and connectivity then the Crown Point Bridge in the late '20's. I think it's easy to understand how important the bridge is after having closed the bridge two years ago in October and recognizing how much the regions both in Vermont and New York suffered and suffered directly and immediately. And so you know it's something when you have a piece of infrastructure that's been there for 80 years you, you take it for granted but when it's not there it's clear how important it is. And so you know I think it certainly gave us a sense of urgency and when I say us, that's everyone involved in the project - the resource agencies, the design team, our environmental folks. Everyone really understood very clearly that this was as urgent a project as there could be.

An architecturally rich site

Building a bridge here is natural from a number of perspectives but primarily from the perspective is the lake is not quite at its narrowest point, but nearly so. And it's just far enough north that there's no really, between Lake George and Lake Champlain. There are other ways and of course going around the southern part of Lake George is a possibility but this is far enough north but not all the way north where the lake is too wide to consider a cost-effective crossing. So it's about, just about right.

Interestingly, in the '20's our sensitivities to archeological resources weren't the same and I can't imagine a more archeologically rich site on either side of the lake. On the Vermont side with almost 10 thousand years of Native American archeological resources and sites, and on the New York side with pre- Revolutionary War and Revolutionary War forts. I mean it's, either site would be the most archeological rich site I've ever worked on as taken separately. So it's really incredible in terms of how many resources there are - and not in the vicinity of the bridge, really along the alignment of the bridge, right underneath the bridge. The forts are a stone throw. You can literally throw a stone and hit not just the one fort but the three forts that had been there in the past.

So it's an incredibly, it's an incredibly important part of the decision making to replace the bridge on the same alignment because moving the bridge anywhere else up and down the lake was evaluated and I can tell you it didn't take long to come to the conclusion that the bridge had to be along, the replacement bridge had to be along the same alignment and had to be really right on top of the existing alignment because anything else would, would negatively impact the rich resources there are on either side of the lake.

I would say we reached out to the public to identify whether there were any other viable alternatives elsewhere and the message came back loud and clear, incredibly loud and incredibly clear, that the bridge needed to remain at this location. Then we did some evaluation of cultural resources and I think on the Vermont side every single shovel full had a Native American artifact and that gives you the sense that there's no question that it's a rich site and that any impacts are negative. So moving the alignment, we were very careful to do two things keep the alignments the same with a very slight shift on the Vermont side to protect the Chimney Point Museum but also that we stay above the ground plane so that we actually lifted the bridge up so that we wouldn't [impact resource]. We then created a buffer zone so that we wouldn't impact any archeological resources and you know that's really the right thing to do in these circumstances. Build along the same alignment stay above the resources and then, in my view, try to do it as quickly as possible.

A unique free form truss design

Charles Spofford created something incredibly unique when he designed the Crown Point Bridge. If you think about the Crown Point Bridge as a structure, the only bridges that look like Spofford's bridge are his other bridges in Cape Cod over the Cape Cod Canal. There are two similar bridges and another in New Hampshire that were essentially an evolution of this form. But this was the first continuous truss that had a free form, that essentially developed from really an under deck truss, to then almost an arch, to then back to an under deck truss. So this freeing the form of an arch in my view was a huge development in the design of trusses.

And part of Spofford's ability to I think push the envelope of what a truss was, was because he was coming up with a new way to analyze trusses. It's another part of what I would say is the heritage of Crown Point Bridge but also Spofford's work is really some seminal ideas of continuous truss design. Now continuous trusses as it turns out are much more efficient than simply supported trusses. This was not only an unusual and beautiful form but it was also a highly efficient form and a rather complex form to design. So he needed to create in many ways the math by which he could design a bridge and you think about it, this is all prior to the computer. What's easy now was quite difficult then and something remarkable about Spofford's contribution as an engineer was not just the design, the built artifact, but also the process by which you could get to that design. So that, in my view, makes it a particularly important bridge but also a particularly important artifact for the engineering community.

Learning from earlier designs

We often, what I would say, is study the works of others and then evolve, evolve these ideas. In fact, my firm, one of their noted bridges is a variation of one of the Cape Cod Canal bridges, the same we sometimes call it a form that's kissing dinosaurs - two trusses that come with an arch and a suspended span. This is exactly a variation on an idea that Spofford developed and that I would say that's very true of engineering. We, as bridge engineers, we design many one-off structures. So we are trying to learn from what others have done in the past; what's successful what's not so successful, and then to improve in every generation. We don't have, how would you say, in your career if you design a hundred bridges, you have a hundred chances to improve. It's not many. And when the bridge survives beyond your practice life, your learning curve, you don't get to learn from your own bridges. So you're obliged to learn from the works of others. I think Spofford's bridge here particularly was one to learn a lot from and not just for me as an engineer but for many engineers particularly in terms of a design of a truss.

What you take from the idea of a continuous truss is that essentially, the idea with a truss, especially in a continuous truss, let me try to explain this and see if this makes sense. The way a structural system works for bridges is that you want depth, the deeper a structure is, is where the moments are the biggest. Now in a in a typically simply supported span, if you just have let's say an abutment and an abutment, the truss would want to be deeper in the middle so sometimes you have an arch or an under slung bridge. In either case that's the right form.

In a continuous truss, your moments are deepest at the piers so you typically have a truss that starts, you know the bottom chord may be horizontal, but the top chord goes up a little bit like a suspension cable. And now if you imagine taking that idea of a suspension cable, which is the traditional form of a continuous truss, and then look at what Spofford developed from that. This idea that you start below the deck, that you come up above the deck, well the truss is deepest at the piers. If you look at a profile of the bridge, the truss does exactly that. It's just the form is free so it takes the truss from below the deck to above the deck and back below the deck all in a continuous form recognizing that with piece-wise straight pieces. This is what a truss is - straight members, a composition of straight members you can make infinitely variable forms. It's funny because we've been mostly, I would say traditionalist, about using more of the suspension bridge form in the design of trusses. So Spofford very early in the development of trusses showed us a different way and we didn't follow it that often and, in my view, to our detriment. There are many possibilities with a truss form and Spofford was showing us the way.

Damaged by lake ice

Some of what we take from a project like this is what caused some of the damage that ultimately resulted in the bridge's closure. Here interestingly the truss and an 80 year old truss especially in a northern climate where you have a lot of de-icing salts, that's a long life for a truss. It's not that we don't have longer, but that's very typically 60, 70, 80 years is what the life of a truss is. Now in this case, the reason we closed the bridge and that the bridge needed to be demolished was not because of the truss. It's not that the truss didn't need some major rehabilitation, it really did, but it was because the piers were so damaged.

Part of the reason, part of the forensics work that we had done, was to recognize that icing and the expansion associated the thermal expansion of the ice sheet, is very likely the principal cause of some of the damage to the piers. That damage ultimately lead to the, to the fragility of the structure and our decision to close it. So part of what we implemented in the new design was really an ice breaking shape so that the ice will ride up the pier and then break off under its own weight.

Also [in the new bridge] some granite armory that's designed to be replaceable so that the ice abrasion, which was clearly evident around the girdle, around the perimeter of the piers that, that there's a protective element too with granite. That's a very traditional use of granite and, of course, this is a part of the country that is really filled, particularly the Vermont side, has got some of the best granite in the Northeast. I think it also makes sense from the perspective of using local materials but clearly we learned that icing, lake ice and icing, is an important design consideration and that we need some armor at the pier level and also a pier shape that causes the ice to break to get a longer life from the sub-structures.

Lake ice behavior

Lake bridges are really unusual. In my 25 year career I've never done a lake bridge. This is my first. You can say not only are lake bridges unusual but lake bridges in northern climates where you have significant icing are also unusual. In fact, part of the way bridge engineering works is we learn from our past projects and past examples and also where we've had degradation and poor behavior. There are not a lot of examples of bridges that cross lakes in cold climates. The few examples there are, that I've been able to find, one in South Dakota has actually been damaged by lake ice, and some repairs had to be made to the sub-structures. That in and of itself is not unusual but when you think that there's literally tens of thousands of bridges over rivers and just a handful of bridges over lakes and now you think about lakes in cold climates, it's [Lake Champlain Bridge] really quite a unique structure.

Part of what's unusual with lake ice is that it's not the flow that causes damage to the piers; it's actually thermal expansion of the ice sheet. Here there's quite a bit of ice fishing and we know what the thickness of the ice sheet is from fishermen and in a good season it will be between one and two-feet thick. Now that's a significant thickness but what happens as the weather changes quickly, especially when the temperature rises, the ice sheet wants to expand. Now ice sheet expansion often times does shoreline damage but if the shoreline is either rocky or there is a long essentially area where the ice can bond to the shoreline as we have here, you get in circumstances where the ice wants to force, in this case the Lake Champlain Bridge piers, force them towards the center of the lake and that can produce really significant forces. At least in our evaluation we think it's very likely that most of the pier damage was associated with this thermal expansion of the lake ice.

The only folks who have done research on this sort of icing and the expansive effect of, of ice sheets, are actually reservoirs. This is where we have this problem, especially against dams where the ice sheet expands and then forces…induces large forces against the face of dams. And, in fact, it gets even worse when the reservoir's level changes so you cannot only create a horizontal force but, as the reservoirs level changes, the ice gets hung up against the face of a dam and produces vertical forces either up or down. Interestingly, the lake level changes quite a bit on Lake Champlain, so the same possibility we have here is that the lake essentially engages the pier. It hangs on the pier if you will, and then as the lake level changes, whether rising or falling, those forces associated with the ice sheet get applied to the pier. So these are circumstances where you don't need ice flows, ice movement, to cause ice abrasion damage. Again the only folks who have really done research on this and what we base some of our evaluations on is reservoirs, the work of reservoirs, particularly in Canada.

Unreinforced piers

The rate of deterioration here, especially for the piers, is interesting because there was a pier repair contract in 1945, fifteen or sixteen years after the bridge was built. So clearly there were some signs of distress early in the life of the bridge. We don't have, unfortunately, the data on what exactly repairs were made and what was the basis for those repairs.

Part of the challenge in a bridge like this was that, and I think Spofford made an unusual decision, but somewhat justified, there's iron ore mines, significant iron ore mines on the New York side. In fact, some of the most productive mines in the world at the time in the late 1800's, so there large piles of what are called tailings, iron ore tailings and I think Spofford got the idea that this is good aggregate. Why don't we look at this for making an extra durable concrete? He was an MIT professor, did some tests at MIT, looked at even the underwater performance because some of the casting was deep underwater and found that this was unusually good concrete. I think at that point that it was so good that he decided that reinforcement wasn't necessary.

We were right at that point where either and it depended, but half the time you would use mason piers or half the time you would use reinforced concrete piers. Plain concrete piers were relatively unusual although there were some engineers at the time who supported the idea of larger more robust plain concrete piers. There were plain concrete piers that were more cost effective and so it was not that unusual a choice but I will tell you from the perspective of the fragility of the bridge, now 80 years later, that contributed to the lack of, let's say, safety of the bridge.

Certainly some of, there were maybe a half dozen pier a repair contracts [on Lake Champlain Bridge], half of them included reinforcements. So they were banding. There is actually post tensioning banding placed around the piers relatively [recently]. I would say in the '70s was the first banding. So there was a fair amount of strengthening work done to the piers themselves. The challenge of putting reinforcement in after the fact is, is that not only is it difficult and this was exposed, so it was part of the strengthening corroded over time. But the other challenge is that you're trying to confine and to strengthen concrete that's already started to deteriorate. The best time for placing reinforcement is obviously when the concrete is cast. And so, of course the longer you wait, the more deterioration, then the more likelihood that your strengthening won't be as effective as it would be, as it should be.

I think the other part of the problem is that over the years, with many repair contracts, you make cosmetic repairs which hide in a way they're, if you will, band-aides over larger wounds. So some of what happens is the structure, the pier sub-structures, continue to deteriorate but they deteriorate behind some cosmetic repairs. I think there is some indication that, that was the case. The piers didn't look quite so bad as they did when you cored into them and did a more detailed investigation.

Spofford's contribution to engineering

As a structural engineer and as a bridge engineer did, [Spofford] did something that was relatively unusual. I would say more so in his generation of engineers, but certainly unusual now, which was he made a major contribution in terms of bridges he designed. If you argue that bridge engineers, the way they transmit ideas is in the built structure, then I would say it's an incredibly important part of his work. But he also was a university professor. So he influenced a generation of engineers, started a firm that was very successful and still remains a successful firm [Fay, Spofford & Thorndike]. But also I would say he wrote some very important literature on the design and the methodology on the design of trusses. And then even to take a step further, [Spofford] developed some equipment specific to the construction of truss bridges.

One in particular was developed and used for this sort of bridge - which was essentially the problem with a continuous truss is that unless you know the reactions, so you have essentially in this case you have four piers you have two interior piers and two flanking span piers. The problem with a continuous system is, is that depending on what the reactions are at the four points, it changes the stress state in the bridge. So one thing you need to know, it's one thing to make calculations, but you need to know in the field what the forces are at each bearing. And he came up with a unique way, a particularly unique way, of having a load measuring tool that's actually a band that would measure the load at the flanking span piers so he could verify that his truss design, that the truss, let's say the construction of the truss, was consistent with his design assumptions.

So you get a sense of what sort of engineer Spofford was. He did it all. He really covered all spectrums of the profession - education, writing what essentially became textbooks on the design of trusses, the built structure itself and even the tools to help build the structure. So a complete, I would say a complete, contribution. Again maybe in his generations that's not so unusual but in our generation of engineers that's really quite special.

Inspired by setting

One question you might ask is, why this shape bridge? We've talked about how Spofford came with quite an unusual shape of this continuous truss. Why this shape bridge in this setting? What's remarkable about Lake Champlain, it's really a valley and so along the lake front, and is really an undulating shoreline, this bridge you can see for many miles. But also you can see in pure elevation, especially from the south looking north, you can see the bridge in profile against the Adirondack Mountains. And so you have this wonderful, let's say, view of bridge and mountain. I think it's very natural for a bridge that has to raise 70 or 80 feet to get above navigational traffic, I think it's very natural then to mimic this in a way, the shape of the mountains in the horizon especially looking from south to north. It must have been an idea in Spofford's head and it must have been part of this inspiration, in my view, exploring this unusual truss form that had no precedent as near as I can tell. And so, even as far as the design of the new bridge, it was hard in many ways to leave that sensibility, let's say, one of the important views is from the Vermont shoreline looking north with the Adirondacks in the background and that somehow that shape, that shape that echoes the mountains the Adirondack mountains in the background wasn't the ideal shape for the bridge. There is always this question about how do aesthetics enter especially in the mind of an engineer who tends to be more focused on brute efficiencies, if you will. And you know I think part of the magic of the site I think is compelling enough so that more, let's say mundane solutions, don't stand up to the site. They disappear too much.

There is this idea to that the bridge and the place interact and the people interact so this is not just about the bridge or the place or driving over the bridge or being along the shoreline but it's how those three interact together. I think that's what makes the site so special but also it's made the public process an incredible special moment.

A very engaged public

I've never in my career had more involvement from the public, more interest in a project, than this project by far. So when we were developing alternatives I can tell you that the mundane alternatives were ruled out immediately, that the more signature, or the more iconic bridges, were the only ones that were worthy of consideration. And that the bridge that echoed, this modified arch, that echoed the shape not only of Spofford's bridge but also I think respected very carefully the views of the bridge and its setting were clearly the favorite of the public and I would say were also the favorite of the design team in both states. And this doesn't always happen, that there's a clear way forward, but for this project it was very clear and it's good fortune because we needed to move very quickly.

I'd have to say that we followed in Spofford's footsteps quite clearly. In fact even in the public meetings we showed the elevation of what we proposed against the backdrop of Spofford's bridge and we did that carefully because that relationship was so important I think - just the sense of the bridge in its setting was so important. We had an incredibly engaged public advisory committee and so we decided to present our ideas to the Public Advisory Committee [PAC]. We called it a PAC plus meeting because there were some other folks involved and even some high school students which was interesting. We presented these ideas and we really only had a week to prepare. So these were more what I would say, even though we developed renderings, they were more sketches of ideas. One was an arch and it was clear from the PAC meeting that the arch was a favorite but Scott Newman from VTrans [Vermont Agency of Transportation] in the historic preservation side of things, he had a wonderful notion about it and he said you know there is something unfinished about the arch, there is something missing. It was at that point where I said you know I couldn't agree more and there's another way to do this and it actually makes the bridge better in a way. And so we did sketch it up right at the PAC meeting on a flip chart and someone pulled the flip chart out and made me sign it as I recall because it was clear to everyone I think at the meeting, that that was the right alternative.

As far as the PAC was concerned, the Public Advisory Committee, that one really captured the sense, an echo of the old bridge, but also something modern and unique. And so it was about eight o'clock. I had half-dozen guys in my office working furiously overnight. The public meetings were the next day. We had [previously] printed large boards and so there was one missing. So we had five alternatives plus one; this [the modified arch] was the sixth. And of course we had boards set up and engineers that were at each alternative to describe the alternative and answer questions and the one we didn't have [on a board] of course was the one we came up with [the night before] that was clearly the favorite.

Based on the, over 3,000 people who voted on the bridge, it was you know the favorite by far. So, that in terms of, design happens that way I think but I would have to say Scott Newman's and I don't know if it was his perspective about the historicity of the Crown Point Bridge, of the old bridge, or just his design sensibility but he said the right words which are, "it just doesn't look finished." You had the arch go into piers, it just didn't; it just wasn't enough. It just didn't sort of engage the lake in a way that bringing the rigid frames down below the arch, really created that same, maybe not the same but a different but a similar moment to what Spofford did. And for me the part that's wonderful about it is that it made the bridge, it integrated the construction, the ideas of construction for the bridge. It integrated it in to the design. And I hope the hallmark of some of my work is that if you look carefully you can see the way the bridge was built in the way, in the form, in the structural form chosen.

The new bridge

In terms of the design, as an engineer I'm a bit superstitious to say too much before the project's done but so far so good. I think the bridge in elevation and in profile really has the sensibilities that I was hoping for. Without the arch in, of course, that's the big piece missing. We are a week or so away from floating in the arch and then I think you will get the sense of the bridge as a whole. It will be more transparent I think than the old bridge and it will look I think a little more delicate. The arch will look a little more delicate but it's, of course, not very delicate, it's not a very delicate structure that I think will be a nice interplay. You'll see really the approaches that I think are robust and the arch which is maybe a more transparent, lighter element and hopefully that interplay works well. I have to say the setting, hopefully the bridge lives up to the setting, and I hope the communities, the regions appreciate the bridge half as much as the old bridge. That would be a pleasure indeed at least for me to see a bridge that has the acceptance of the region really, or the appreciation of the region.

This project is an incredibly different project from so many different perspectives, but I would say its pace for one. From the designers' side, ten weeks to design a major bridge is the fastest of any project we've done but that being said, I think the real heavy lifting for this project was the getting through the environmental process. When the ferries were in service the states of emergency where removed from both sides [New York and Vermont], so we had to follow all the environmental regulations in a time period that would typically take years with the resource agencies with so many resource agencies, 40 or so resource agencies. On this project, it would take, something that would take years, we did in six weeks. When I say "we" I'm speaking of the larger project team and the resource agencies - that's the federal government, the Coast Guard, the Army Corps of Engineers, the states [New York and Vermont] with different jurisdictions and different rules on each side of the lake.

It's an incredible complex process and I can tell you in my career I've never seen so much urgency put for getting this project through the process with no, we followed every, every, there was no short cuts taken in the NEPA [National Environmental Policy Act] process and it does in a way suggest that we're sometimes at our best when there are emergencies, that we especially as engineers but also the public agency side, the resource agencies side. We can really do better if we have the right sensibilities and the right alignments.

"It was breathtaking"

And the other thing that was hugely important to my staff in all of this was coming to the public meetings and seeing how important this bridge was to the public. That adds gas to your tank if you will. If you're staying up late and, no one had any time off I can tell you in that 10-week period and many all-nighters, it was like being in college again. That adds gas to the tank, having the public really appreciate your work number one but also to recognize how important such a project is to the public and to the region. So that was a huge part of what makes this project special, at least to me and to my guys, my engineers.

Well, you know it is unique but it's hard to be sitting here on the shoreline of Lake Champlain and look at how much the bridge really is the most significant built structure in I would say 100 mile radius. So I would say it affects everyone's lives. It's in everyone's horizon, in their background. How could it not be important to the regions? And you know I think it's one thing for it to be important; it's another thing for people to really participate.

I think it's also pivoting from really being angry about losing a vital piece of infrastructure, a vital piece of connectivity, where both regions rely on each other economically and for things like social services, for things like the fire departments and the hospitals. To pivot from let's say being angry that this important link is closed to then being supportive of a new design and really getting this bridge reconstructed that happened in a matter of weeks, I have to tell you it was breathtaking. It was breathtaking to everyone involved in the project. I think it was probably breathtaking to the public. It was really from, from anger to tremendous support, yeah that was that was breathtaking in that respect.

First thoughts – rehabilitate the bridge

When we first were engaged in the project it was an environmental project so we were only to establish whether the bridge should be rehabilitated or replaced. In my gut at the time was that, when we won the project actually in 2007, was that that bridge would very likely be rehabilitated. In fact, knowing how important the old bridge was to the region I thought it would be very difficult not only to replace the bridge just from the perspective of the public but that it's such a piece of history to the region that somehow having to abandon such a piece of history is difficult. And that's particularly difficult in this part, at least in my perspective, this part of the Adirondacks and this part of Vermont because history is such a crucial part of life here, in tourism and a sense of place. My sense was at the time that this would be a rehabilitation project and a complicated one because there was significant rehabilitation required.

Our first meeting on the project was a site tour. Another engineer from my office and I had the pleasure actually of visiting the bridge. We had, the bridge was closed to only one lane of traffic and there were some emergency steel repairs. And so we got a chance to walk the span and look at the truss and I really thought that, I had seen a lot of old trusses and I really thought the truss was not in that bad a shape, that it was rehabilitatable, if that's a word. And so I thought that it was very likely that we would rehabilitate the bridge from the perspective of the truss.

And then we had the opportunity to take a ride on a boat. There was some inspection work being done so there was a boat available. We took the boat around the piers and this was in early September [2009] and the lake level, this is when the lake level is the lowest, and so the piers really looked that there was a fair amount of abrasion damage and deterioration. Tom Hoffman, the regional structural engineer from New York State, he was conducting the tour. I mentioned to him you know the truss, we're not going to replace this bridge because of the truss, the piers have me nervous.

About two weeks later the lake level lowered significantly, another couple feet, and Tom had the presence when he was out there to take another look at the piers and identify that there was even more damage to the piers as the water level receded and had the presence of mind to order some cores -really coring into the piers to identify the health inside. That way you can see deep inside the pier and the cores were, the result from the coring were, not a positive at all. In fact, deep into the piers there were significant cracks and the petrographics, the examination, indicated that there was not only some freeze thaw damage but there were telltale signs of the aggregate separating from the cement base. This is, let's say you're on the way towards, it's cancerous in a sense for concrete.

Concerns about bridge safety

So that got us very concerned. If you imagine that the pier is ten foot in this dimension, maybe two feet of the piers were severely deteriorated, so you've essentially taken quite a, how would you say, the ability of the pier to behave itself to carry loads, that's been compromised. So we were getting more and more concerned.

At this point we did some calculations to try and speak to the safety of the bridge and it was clear from those calculations that we couldn't, we couldn't argue for the bridge's safety and it's at that point that we recommended the bridge be closed. NYSDOT's [New York State Department of Transportation, George Christian at the time had some experiences with bridges that failed abruptly and understood exactly what we were talking about - this unreinforced concrete and the potential for abrupt failure. We had the conversation at ten in the morning and I would say the bridge was closed by one. So it was a, see it was a very significant, I would say interchange, in terms of our assessment of the piers.

Then at that point, once we closed the bridge we very quickly embarked on this on investigation to make sure that we were right. And our whole premise at that point was to try and get the bridge open by snowfall, by the time the snow flies. So the problem is, with this region, that the only alternate is the Ti Ferry, the Ticonderoga Ferry, which it doesn't operate over the winter season. It's a cable ferry, so this becomes in the circumstances where you have the bridge out, let's say, in the winter time, the detour becomes a hundred miles and a hundred miles in the wintertime in this part of the country is terrible. So our goal was to rehabilitate the bridge in the sense we were trying to assess what the degree of damage was up and down the pier.

More inspection of bridge piers

Our idea is if we're going to fix this area and we have damage below, we better find out what damage we have below immediately. So we recommended a dive inspection and with the zebra mussel infestation that you have in this part of the lake, that represented its own challenge and some of the piers are in such shallow water they're hard to get to. So the dive inspection happened, relatively speaking, immediately.

We also instrumented the piers. The expansion piers are supposed to not move longitudinally as the temperature goes up and down. The expansion piers, the bearings, are supposed to slide. That's the way the bridge was designed and unfortunately, when we put the instruments on the piers we were able to show that as the temperature went up the pier rocks towards the shoreline. As the temperature went down the pier rocks towards the center of the lake. This is exactly the behavior that shows you that, not only is the bearing not functioning, but also the pier is rocking about a point where it's severely damaged. This is exactly the part of the problem that lead us to, not only confirming that we, that it was the right decision to close the bridge, but also that rehabilitation was going to get to be more and more of a challenge because the dive inspection revealed that there were cracks not only at the water line but there were cracks around the perimeter entirely of the pier, maybe eight to ten feet below the water line. So that represents a crucial problem in that not only do we have to fix the pier right at the water line, we can do with some techniques, but that the pier would have to be repaired deep under the water.

That is a huge challenge from a design and construction perspective, especially with icing in the lake. With lake ice any work in the wintertime becomes problematic and so here we are with the ice-producing circumstances where the bridge becomes more fragile because we're arguing that the ice caused some of the damage, it makes construction very difficult. The degree of damage, the more we look, the worse it is. So these three ideas contributed to some tough decisions having to be made and looking at alternative sites in the November time-frame pretty well indicated that we needed to replace the bridge on its alignment.

Difficult decisions

One of the great challenges of the project on the side of construction and must have been part of the original construction as well, was the fact that you had very good rock but it's very deep and it's also overlaying with very soft muds, muds I would call the character of toothpaste yet so soft that they can't support any loads. The mud is maybe 50 or 60 feet deep so you have 30 or 40 feet of water at mid-span and 60 or 70 feet of mud. And the problem with this mud is that if the bridge were to collapse along its alignment the bridge would be buried in the mud so that we wouldn't be able to retrieve it. If we can't retrieve the bridge, the existing bridge from the mud, then putting in the foundations for the new bridge would be hugely problematic. In fact, even when we did the demolition in late December, we cleared most every but not every piece and we had two shafts that actually had a conflict with some remnants of the old bridge and caused some delays for the project and that was anticipated.

One of the challenges and it's a major challenge really, with declaring a bridge unsafe or closing a bridge is that you are in a difficult position. As an engineer and I think the way I phrased it to George Christian at the time, was that I can't speak to the bridge's safety. I don't think it's going to collapse anytime soon but I can't guarantee it won't. This becomes the problem with decision making that I can't speak for its safety. I can't make a calculation to show me that the bridge will remain stable. And we were treating the piers at the time as essentially piles of rubble. If you're cracked all the way through, the bridge's behaving in a way like a masonry pier and this represents a huge challenge because I don't believe the bridge was in any danger of collapse directly. But I can tell you that when ice came and with large thermal movements, and it's quite a windy site, these are all things that contribute to the piers potentially becoming destabilized.

The downside risk, and this is the problem in many cases with engineering, the downside risk of the bridge collapsing, you would have loss of life, even for construction personnel if they were adjacent to the site. You have this horrible problem of bridge removal and schedule delays. So you're taking what's already a terrible problem and potentially making it much, much worse. And you know, these are difficult decisions to make and ultimately was made by NYSDOT at the highest level, by George Christian, But at least for me, my recommendation was quite clear that I couldn't speak for the bridge's safety and that the event that the bridge collapse could be quite sudden with no warning.

We have many circumstances in bridge behavior where we have plenty of warning. We'll see signs of distress. You can go out there and measure the bridge misbehaving on its way to collapse. With reinforced concrete, you have that ability. With unreinforced concrete it can go, it can really fail abruptly, and the larger the section is, and these are large unreinforced piers, the more likely you have an event that, and it's partly because, and I'm not sure if this will make since to anybody, but the energy associated with fracture is bigger than the resistance of the section. So it's really like a rubber band snapping in a way. It's an abrupt failure and that abrupt failure is really what we really were concerned about. No warning, an abrupt failure, and then what's already a bad day of having to close a bridge, becomes a horrendous problem in terms of reconstruction and also the potential for loss of life. The huge problem with an abrupt collapse like this is you have first of all loss of life potentially and, second of all, a tremendous problem with reconstruction.

With demolition in this circumstance where we have these very deep muds, the big challenge is to make to make sure that the truss is in small enough pieces that it can be essentially pulled from the lake and that the hope is that it doesn't sink to far into the lake bed so that retrieval is difficult. Now in the Mississippi River when we do this, sometimes we actually attach a buoyancy, sometimes 55 gallon drums, empty tanks, so that the pieces will float and then can be picked out of the water.

Given the time frame with winter coming and the fragility of the piers, we really didn't have time for that so the idea, and if you look at the explosive demolition video or some stills, you'll see that the truss was, there were explosions at many points along the truss, and the idea there was to break the truss into small enough parts that it could be easily retrieved and we left the decks lab in place. So the demolition you can see many point explosions if you look at the demolition video and that's to break particularly the main span into enough pieces so that it's easy to retrieve from the lake bed and particularly we left the decks lab in in the idea that the decks lab would essentially help the sections float on the mud not on the water of course on the mud. I would say generally speaking retrieval, demolition happened on December 28th and retrieval went forward relatively efficiently with not too much difficulty. Of course it's very deep water and the challenges with the mud did present themselves.

The approaches also, we didn't of course, the rock comes right up along you can see the rock daylights on both the New York and Vermont side. So the approaches you didn't have to break into small pieces and you can see that they were left in large pieces and that was the easy part of the demolition. It's the span in the middle of the lake; that's the great challenge. I would say that we put in 32 shafts [for the new bridge] and had two that had interferences with what we imagine was the old bridge. So that's, I would say, the site was relatively clean with most of the bridge, the old bridge, removed.

There's one other component to this which is interesting which is that, and I'm somewhat involved in this, or really directly involved with this, is that we're doing quite a bit of research on the way old steels behave under blast loading. And so, the bridge, actually the portions of the bridge, in a way it's like being an organ donor, were used by the Department of Homeland Security and the US Army Corps of Engineers to look at the behavior of old bridge steels under explosive loading or rapid loading. The experiments are on-going as we speak and the results have been very, very interesting.

A network arch

This a little bit of a challenge because it doesn't have a name and the modified network arch which we used in the public meetings is probably not a very good name. It's a network arch and by network it means that the cables cross at least twice. This represents a more efficient system in many ways but also a system that's more resistant to damage and is easier to replace the cables. The flanking spans, if you will, are rigid frames so I would say in a way this is a, there is no good name for it, but it's a network arch supported on rigid frames. I think in a way it strides to be a really integrated system but it's really an arch supported by rigid frames. See you can't ask an engineer to name something!

It's quite a unique design. I would say there is only a half dozen or so bridges in the US which use crossing cables and I've been, let's say, fairly, directly supporting this type of bridge arch bridge over others. In fact, I feel that an arch bridge with hangers across twice is so much safer then arches with vertical suspenders that arches with vertical suspenders shouldn't be permitted. So Lake Champlain in a way is an example.

The new bridge is an example of what I hope to be the future of arches and it has a remnant of covered bridges, particularly the town lattice truss which are, if you imagine, a wood truss, where you have diagonals that cross each other many times. It really looks like a lattice, almost like a lattice fence. That system has got the same character as the crossing cables and the beauty of these old wood trusses is often times they're terribly damaged. You got rot along the diagonals but they still stay up. In fact, usually we replace the floor system in a covered bridge long before we replace the superstructure and that's because the system is wonderfully redundant, wonderfully able to redistribute loads in case you have one or two elements damaged. That same character in my view is what makes this sort of arch a much better than an arch with vertical hangers and, in a way, I think it's also a nice, there's certainly covered bridges on both sides of the lake in this part of the country and there's a nice, let's say, echo of that technology, which in a way has been forgotten by bridge engineers. You know sometimes I think we look at timber trusses as purely historic structures, but we have much to learn from these structures. This idea of crossing diagonals, in my view, is a wonderful structural system and something we should, we should explore more carefully in future projects.

There are two or three levels to think about what I bridge means I would say. In a sense, part of it is the physical connection between places that weren't, wouldn't otherwise be connected. So for the regions here, if you will, that it's essential character. But also I think if you're not using the bridge it's in your horizon, it's in your, let's say, in your perspective so that it changes the landscape. I think that has an important moment, particularly for this bridge which is so visible in this valley setting and against the lake.

But also the bridge is an artifact. It's an exploration of some ideas by engineers which hopefully are shared or improved in the next generation of engineering and bridge design. So if there were a Hippocratic Oath for engineers, I would say it's something along the lines of, discontinue my bad ideas and improve my good ideas and so hopefully there's some good ideas here that live in new bridges in other places and that the ideas that are not so good get corrected in future designs. And I think that's the long, how would you say, if you look at bridge engineering as a practice, there's a long history of that. To the extent that this is a contribution in that continuum of exploring ideas, again I hope the good ideas that are here are further improved and the bad ones are killed unceremoniously.

I would say what would seem like success, what success would look like on this project I would say for it [the bridge] to be opened as soon as possible, for it to have an extraordinarily long life and for it to really add to the spectacular vistas that you have along the lake."