Lone Tree Bridge

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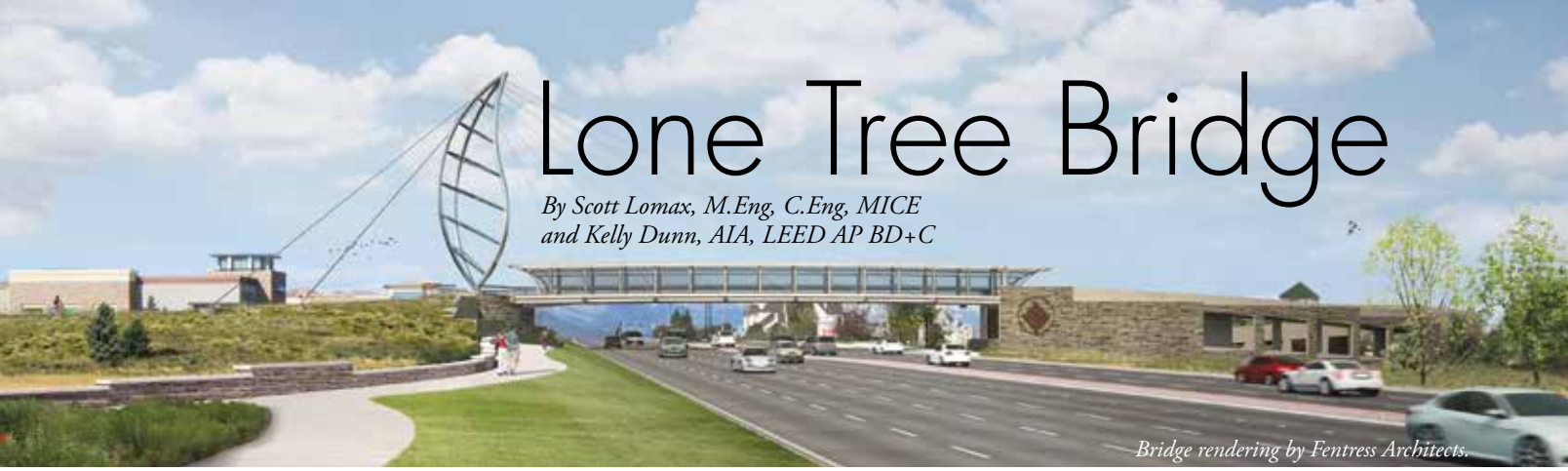


Bridge rendering by Fentress Architects.

Pedestrian bridges capture the imagination and have the potential to transcend conventional design. There is a long history of landmark bridges created by some of the industry's greatest engineers and architects. However, the overarching aesthetic demands an integrated approach. This article discusses the historical context of signature pedestrian bridges and showcases the tools and processes that facilitate an integrated design approach, using the example of the Lone Tree Bridge in metro Denver, Colorado, designed by Fentress Architects and Thornton Tomasetti.

Background/Historical Context

Throughout history, bridges have been seen as pivotal links in infrastructure, the means for the consolidation or expansion of a community, a testament to progress in terms of design and materials, and above all, landmarks. The raw nature of these objects appeals to a wide audience, and enormous civic pride is captured in the expression of a crossing. While there are many historic precedents such as Pont des Arts in Paris or Venice's Ponte dell'Accademia, in more recent times, there has been a significant increase in the design of signature or landmark pedestrian bridges. Projects such as Gateshead Millennium Bridge in the U.K., Langkawi Sky Bridge in Malaysia, or the Puente de la Mujer in Argentina have raised the profile of pedestrian bridges, and owners are aware of the impact such designs may have on the urban fabric.

Aesthetic through expression of the structural behavior is not a revolutionary concept. The work of artists such as Nervi, Candela, Dieste, and Calatrava, among others, resonate through a deeply rooted integration of architecture and structural engineering. Indeed, as Candela once stated, "Structural design possesses more art than it does science." The attraction of the purity of bridge design has fascinated many famous designers, and the most successful projects are a result of an integrated approach combining architecture, engineering, and an appreciation of constructability.

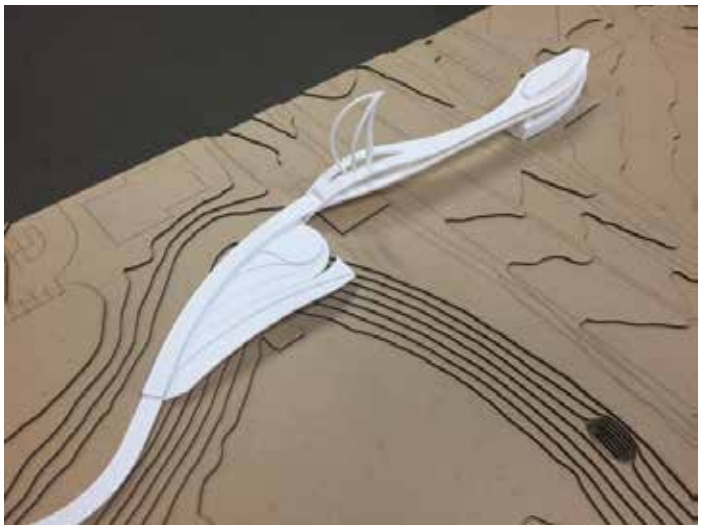
Puente de la Mujer.

Context plan by Fentress Architects.

Approach

The success of a project depends on clearly identified goals and objectives, which is more difficult that it sounds. Each project has its unique circumstances and challenges that must be analyzed on a project-specific basis. It starts with basic requirements such as length of span, followed by clearance envelopes, a discussion of cost and schedule, and then on to intangibles such as an improved quality of life and a catalyst for development. From the outset, the challenge is a combination of practicalities, such as constructability or the contextual design of a signature component. The process demands varying skill sets and experience, as well as integration between architect and engineer. For the Lone Tree Bridge, the most basic requirement was to provide a 170-foot crossing over Lincoln Avenue in Lone Tree, Colorado.

A closer look showed the need to connect communities and provide an essential link in a network of cycling trails. A more aspirational outlook was to create a landmark that would represent the ambition of the city and be respectful of the amazing natural beauty and vistas of the nearby Rocky Mountains, yet be functional, practical, and within budget. Several concepts were developed, and designs pushed, pulled, and tested. Sometimes this led to minor tweaks, while other times to seismic shifts in the form. Some of the tools available, such as advanced computational modeling (ACM) and 3D printing, were useful during the early stages. However, the principal mode of communication was through hand sketching, preliminary hand calculations, and a mutual respect for the experience and insight that each team member brought to the table.



Overall massing model by Fentress Architects.

As the core form of the bridge – an asymmetric cable stay – began to take shape, the analysis and sculpting advanced further. With an efficiency of form founded in the basic layout, the design team focused on the sensitivities of the cable and pylon geometry to create a balance between structural efficiency and art form. Paying homage to the symbolism of the client (the City of Lone Tree), the team refined the pylon to an elementary leaf while retaining the structural integrity. The pylon is essentially a three-dimensional lattice truss, constructed of industry standard elements with a twist in the geometry to create a sculptural form.

As the form and vision were consolidated, a number of studies were undertaken to investigate member and material options. The benefits of a lightweight, slender yet stiff structure led to the selection of a steel pylon and deck with a precast concrete walkway. The main legs of the pylon are 24-inch-diameter and 18-inch-diameter for the front and rear legs, respectively. The use of pipe section helped reduce the amount of welding on the project, proved convenient for the intersection of the nodes, and provided a softness to the pylon in keeping with the aesthetic intent. A wall thickness of one-inch was selected to avoid changing thickness, which would incur a splice, and to avoid local stiffening or high stresses at the anchorage connections. This balance of artistry, engineering efficiency, and practical construction was a recurring theme throughout the design and design-assist process. Twin backstays anchor the pylon and the forestay cables splay to support the deck at 24-foot spacing. The 12-foot wide deck is connected to the cables via outriggers that cantilever from the deck sufficiently to ensure the cables do not conflict with the enclosed walkway. The deck is defined by an in-plan truss created by longitudinal edge beams, crossbeams, and diagonal bracing – all using conventional rolled steel members. The main span has an enclosure to protect users in severe weather yet enables one to enjoy the open air and direct sunlight on nice days via a stainless steel mesh on the sides and an ETFE roof. A simple portal frame, supported on the main span deck, provides the infrastructure for the enclosure.

As with many pedestrian bridges, the final sizing was a balancing act between strength to carry the imposed loads, stiffness to yield acceptable movements under use, economy through efficiency of sections, type of member and detailing, and attention to the aesthetic vision. The pylon is a signature component, and the member selection and connections were honed with architectural input. The deck was required to be slender for both aesthetics and to maintain the clearance envelope without added depth, which would have a knock-on effect of increasing the approach spans. However, the member types could be conventional, which helps the overall economy. The cables help to yield a lightweight structure, but both redundancy and dynamic behavior became key criteria in the design and were studied in detail. The dynamic behavior, in particular, required time-history analysis of user-induced vibrations to simulate occupancy and determine acceleration levels.

Tools

To work fluidly and communicate effectively, the team used a number of different software packages as the project advanced. From early Sketch-up files through to Revit and then Tekla for the fabrication process, the geometry was developed and shared among the team. The team also developed parametric models to create multiple analysis models and test global configurations to optimize the form. The design team used software to import geometry files into analysis models and then export from analysis models back to the geometry files. This enabled direct communication between the architectural and engineering team, and facilitated a smoother process. Tools and ACM were an integral part of the process; however, it is important to note that they did not drive the design intent. The design was conceived, developed, and finalized through sketches, physical models, and drawings. It was an artistic process rather than a mechanical one.

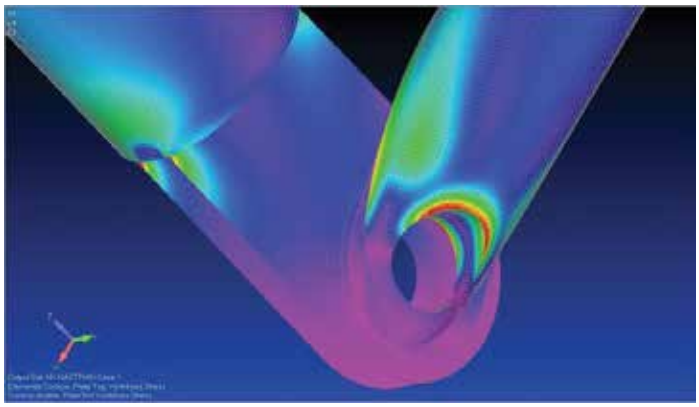
Process + Design Assist

The client made a decision to follow a design assist approach and engage a contractor early in the project. Once the design concept was consolidated by Fentress Architects and Thornton Tomasetti, and vetted by the public via consultations, the next hurdle was to ensure the vision was realized within the schedule and budget constraints. The overall project cost was set at $6.8 million, with a design period of eight months and a construction schedule of 12 months. By integrating the contractor into the design process and using Guaranteed Maximum Price (GMP) milestones, the client reduced cost and schedule risk. For a long-span signature project, the design assist process was also invaluable to develop and finalize the design with input from the industry. Conventional project milestones of SD, DD and CD were replaced with IGMP, GMP, and Mill Order. The design team worked live and directly with the contractor/fabricator to develop options and select details, and received immediate feedback on how they would impact schedule and budget. The process helped control the quality of the final product and reduced risk across the project. Design assist is a loosely defined process and can be of enormous benefit if correctly applied. Some key requirements include:

- Engagement of the contractor at the correct stage of project development. Balancing sufficient design development to show feasibility, intent, and consolidation of principal

Architectural rendering by Fentress Architects.

Local FEM of the pylon base pin.



Stress contour map.

requirements, yet allowing enough latitude for the construction team to have influence.

- Selection of the most appropriate construction partner. In addition to cost and experience, the understanding and willingness of the contractor to engage in design assist in a collaborative manner is paramount. The contractor must understand the design goals, and the entire team must be committed to achieving the balance of cost, schedule, and quality.
- Respect for the experience and skill set of the various parties. Essentially, for design assist to be successful, the design and construction teams must work toward common goals and value input across the board. Clarity of the objectives and challenges is key, followed by effective communication.

For Lone Tree Bridge, general contractor Hamon Construction and steel fabricator King Fabrication joined Fentress Architects and Thornton Tomasetti during Schematic Design. Their input, knowledge, and expertise were fundamental to advancing the project. A series of charrettes and workshops created a common understanding of the issues, and open lines of communication facilitated the platform to work through solutions. An example of this was the pylon base – a joint that was not only of huge engineering and architectural significance but would also be influenced by the fabrication process and the erection requirements. The use of a sculpted pin connection provided a strong yet artistic architectural expression, and was in keeping with the contractor's preferred erection scheme whereby the pylon would be assembled flat and rotated into position. The engineering team worked closely with the fabricator and developed local finite element models of connections to optimize the configuration and sizing.

Design assist is not necessarily the correct approach for every project; however, in the case of Lone Tree Bridge, where an outstanding team was assembled at the critical project milestones with experienced, committed, and passionate individuals, it has been a success to date.

Summary

The most successful pedestrian bridge designs are often pure in their concept. There is an elegance to their simplicity and form that transcends conventional architecture and engineering. To deliver such a project requires an integrated process starting at conception and continuing through the design development and construction. It is essential that the design is influenced by architectural, engineering, and construction principles. Lone Tree Bridge is a wonderful example of an educated client; a balanced, experienced and focused design team; the exchange of ideas and tools to communicate effectively between parties; and integration of constructability with the design process.▪

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