

Case Study: Design of pedestrian timber bridges in an AE Studio

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Summary

California State Polytechnic University, Pomona recently approved an interdisciplinary design course (AE Studio) in which architecture and engineering students work in teams to design a pedestrian timber bridge. The course is structured as a progressive competition and the project sites are selected based on real needs. For the first three years of the course, the project site was on the Cal Poly Pomona campus. For the past two years, the project sites were located in the Angeles National Forest at locations in which pedestrian river crossings were needed. In one case the bridge improved access from parking and day-use facilities to a hiking and biking trail; on the second site the bridge provided an alternative to fording a river to continue on a scenic hiking path. Both project sites were selected through collaboration with the local U.S. Forest Service engineering office based on their future needs and opportunities for funding. In this paper the architecture and engineering faculty who developed this course share selected works of their students and discuss their pedagogical experiences in teaching this type of course, including a discussion of the benefits of using timber as a material and the pedestrian bridge as a type of structure for this kind of class.

Keywords: timber, bridges, pedestrian, education, studio, wood, architecture, engineering, collaboration

1. Introduction

Wood is one of the oldest and most environmentally sustainable construction materials. Approximately 90% (U.S. Department of Housing and Urban Development, 1994)[1] of all residential and 11% of non-residential (USDA Forest Service, 2008) [2] structures in the United States are built using sawn lumber and engineered wood products. These modern engineered wood systems require specialized design and materials specification knowledge. However, despite the need for education in this area, a significant number of civil engineering programs do not offer timber design at all, or offer it only sporadically, or as part of another course. A recent survey (Cramer, 2011)[3] indicated that just slightly over 50% of civil engineering programs offer a wood design course.

In architectural programs, the use of wood as a structural material, other than light wood framing in residential projects of four stories or less, is not common. This can be traced to a limited understanding of engineered wood as a structural material and the perception that it lacks durability and flexibility in form and has low fire resistance qualities. However, recent conservation efforts and sustainability concerns have appropriately elevated wood as the only sustainable structural material. Advances in engineered wood products development and product enhancements have renewed interest in non-residential uses of wood as well as in the use of mass timber in mid- and high-rise residential buildings. Engineered wood is being successfully used for multi-story construction, large span structures and pedestrian and vehicular bridges.

The lack of knowledge of a material can often cause reluctance to use it by the design professionals, or, when used, result in improper use and subsequent disappointment with its performance. It is important that architects and engineers are well educated in the strengths and weaknesses of materials and work collaboratively to ensure their proper and effective implementation. Most, if not all, of the learning related to collaboration between the two professions currently occurs in the workplace. It would be valuable to provide engineering and architecture students with an educational experience that will launch them on the path of mutually beneficial collaboration as they enter the professions.

This interdisciplinary design course (AE studio) provides an educational experience in AE collaboration, the design of long span structures and the creative use of wood as a structural material. The choice of a pedestrian timber bridge for this type of course was made for several reasons: (1) it requires close collaboration between architects and engineers from the beginning of the design process; (2) pedestrian bridge loading is simpler and lighter than that for vehicular bridges; (3) the use of wood required the students to understand its material and structural properties and their impact on the forms they chose to develop. The AE Studio is an exceptional educational tool that should be promoted and supported by the wood industry. The timber projects designed by the students during this course are presented in this paper in an effort to: (1) encourage collaboration between architects and engineers during the educational process; (2) demonstrate the creative designs of pedestrian bridges using wood as a structural material and; (3) involve the community of design professionals and the building industry in the educational process.

2. AE Collaboration

The idea of a collaborative relationship between architectural and civil engineering programs is by no means a new concept, but its implementation in undergraduate education is certainly not trivial. It requires engineering faculty with a level of expertise different from that of a traditional academically trained faculty member, an educational methodology that works for both disciplines and the selection of projects that are responsive to the educational objectives. Cal Poly Pomona presently offers civil engineering degrees within the College of Engineering and architecture degrees within the College of Environmental Design. The emphasis on structural engineering is typically addressed through technical electives in civil engineering. The AE Studio (CE471 – Interdisciplinary Architectural Engineering Design) is one such elective.

3. Course Structure

The CE 471/471L is a 3/1-unit 10-week course divided into three phases. The first phase is two weeks long and is devoted to case studies of existing timber pedestrian bridges by interdisciplinary teams of architects and engineers and to the development of individual design concepts for the assigned project by architects, with input from engineers. At the end of the first phase the students present their case studies and their design concepts, and around eight or ten concepts are selected and approved by the faculty for the next phase of the course. At this time, AE teams are formed to develop preliminary designs of the selected concepts, which they work on for three weeks. At the end of this second phase, the AE teams present their designs to a panel of practicing engineers and architects. Each project is rated on ten criteria (Gershfeld, Sheine and McGavin 2011) [4] and four or five projects are selected to proceed to the third phase. The selection is made through a combination of the panel's objective scoring and the faculty's subjective input. The teams are expanded by absorbing students whose projects did not make it into the next phases. The final phase of the project is five weeks long and involves design development work. The teams develop $\frac{1}{4}''=1'-0''$ scale models of their designs, produce renderings, animations, structural models, structural calculations, and details, build a $1''=1'-0''$ scale model of a section of their bridges (or, in some cases, a $3''=1'-0''$ scale model) and prepare posters and digital presentations. Their work is presented again to the panel of practicing architects and structural engineers, who again rank the projects based on ten criteria, and the winning design is selected based on the ratings of the professional panel. The ten criteria on which the projects were evaluated were aesthetic quality, originality, functionality, response to context, structural integrity, structural modeling, constructability, AE collaboration, cost effectiveness and finally, overall impression.

4. Student Projects

It is not possible to present the totality of the work generated by the AE students over the five years this course was taught. Thus, only selected works of the last three years of projects are presented: Winter 2010, 2011 and 2012.

4.1 Winter 2010: College of Engineering Bldg 9 and Bldg 17

The project site is located on the campus of California State Polytechnic University in Pomona (Figure 1).



Fig. 1 Project Site, California State Polytechnic University Pomona, College of

The project involved the design of a pedestrian bridge connecting two College of Engineering buildings at the second floor. The bridge had to: (1) accommodate pedestrian traffic; (2) provide social areas for students to congregate between classes; (3) serve as a learning tool for various civil engineering classes; (4) be sustainable; and (5) become a recognizable symbol of the College of Engineering. The distance between the buildings was 72 ft and a minimum of 14 ft vertical clearance and 25 ft horizontal clearance for emergency vehicle access was required between the supports. In addition, it was desirable to avoid transferring loads to existing buildings. Students performed their own survey of the site

and prepared a site plan and a $\frac{1}{4}''=1'-0''$ scale site model. The structural design criteria for the project was established based on the latest IBC, ASHTO and ASCE 7 code requirements and were as follows: Live Load - 80 psf, Wind Load - 110 mph (3sec gust), Exposure B, Seismic Load: S_s and S_1 based on USGS Hazard Maps, Soil Class C. The engineering students were required, based on the initial architectural designs, to evaluate alternative structural systems, perform preliminary analysis (napkin level design) without the use of any structural analysis software, followed by simplified, but more detailed, 2D analysis; complete 3D computer analyses were performed for the final designs. In cases in which the design was too complex, early use of computers was allowed and in those in which the design was too simple, 3D computer analyses were not required (these were standard requirements for the course and will not be repeated for the projects presented from other years). The two projects presented here are, Space Truss Bridge and Ridge Bridge.

4.1.1 Space Truss Bridge



Fig. 2 Space Truss Bridge (1st Place), Architects: Nathan Houck, Greg Sagherian, Robert Yamnitz, Elane Yiu, Engineers: Bethany Lopez, Daniel Mourad, Ryan Turner, Samson Wong. Original design concept by Robert Yamnitz.

The winning design for this project was a space truss bridge. The rendering of the final design is shown in Figure 2. The bridge support structure is a space truss formed by three irregular triangles with their bases forming an upper triangle and opposite vertices providing bridge supports. The space truss provides a stable structural system and a symbolic representation of engineering. The bridge deck is suspended from the three vertices of the upper triangle in some places and supported by the legs of the triangles in others. The stringers that support the deck are suspended from the space truss vertices with steel cables. The bridge deck was designed using CLT panels to provide a slim profile and to develop the necessary horizontal stiffness. The final computer structural model of the bridge using

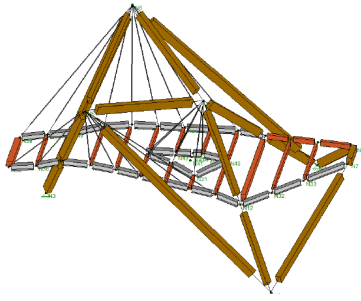


Fig. 3 Computer Structural Model of the Space Truss Bridge in RISA 3D

RISA 3D software is shown in Figure 3. All supports are modeled as pins, members as frame elements and connections as hinges. All components of the space truss are continuous members.

The members of the space truss were Alaska Yellow Cedar Glulam beams, a locally available naturally decay-resisting wood species, with the longest member approximately 50 ft in length. The unique angles of each joint of the space truss required the design of customized connections and each vertex was designed to accommodate steel hardware capable of transferring structural loading and providing aesthetically appealing details. The students explored a number of possible

solutions to ensure that the connections were visually appealing and also provided acceptable load paths. The 10-week course allowed limited time for connection development and only the conceptual design of key connections was completed.



Fig. 4 Deck stringers cable support connection

In designing the deck suspension system students had to address wood's weakness in resisting tension perpendicular-to-grain and designed connections to avoid this type of behavior by using steel straps around the stringers. (See Figure 4)

The bridge uplift issues were addressed by introducing a continuous stiffening beam above the deck along the perimeter of the bridge that also served as a bench. This project successfully addressed the project requirements and received the highest total score for all categories and the highest overall impression score from the panel of reviewing professionals; the faculty concurred with the professional panel.

4.1.2 Ridge Bridge



Fig. 5 The Ridge Bridge(2nd Place), Architects: Bridget Flecky, Eubie Han, Edward Kung Engineers: Gean Na, Alex Quinonez, Fernando Sesma. Original Design Concept by Eubie Han

The runner up project, the Ridge Bridge, was equally impressive. The continuous curved glulam beam supported by inclined glulam columns provided an aesthetically interesting support structure for a suspended bridge deck, conceptually similar to a ridge beam-rafter roof system. The bridge deck was suspended from the ridge line. The

foundations supporting the sloped columns also served as sitting areas for students, thus creating a gathering space under the bridge. The detailed description is omitted and only an overall image of the design is provided to illustrate the aesthetic quality and creativity of the students' work.

4.2 Winter 2011: Angeles National Forest, West Fork Station, San Gabriel River

This project site was selected through discussion with the local U.S. Forest Service engineering office. The site had an existing parking lot and day-use facilities; however one of the most popular hiking trails was located on the other side of the river. Visitors used the nearby highway bridge to walk across the river, creating potentially dangerous situations for themselves and drivers, as the bridge was not designed to accommodate pedestrian traffic. The U.S. Forest service proposed to build a pedestrian bridge from the day-use facilities to the hiking trail in order to improve access to the trail and increase safety. The site plan of the proposed design (note the ramp) is shown in Figure 6. The U.S. Forest Services required that ADA standards were complied with for this bridge, since the trail quality, also serving as fire access from the main road, could accommodate handicapped persons. This constraint, due to the large difference in elevation between the day-use facilities site and the trail on the other side of the river, as well as insufficient space for visually appealing ramps, required a creative solution. The students were permitted to choose a bridge location that best accommodated their designs. The bridge spans, depending on the selected location, ranged from 110 to 140 ft. The winning design, Quadra Bridge, is presented here.

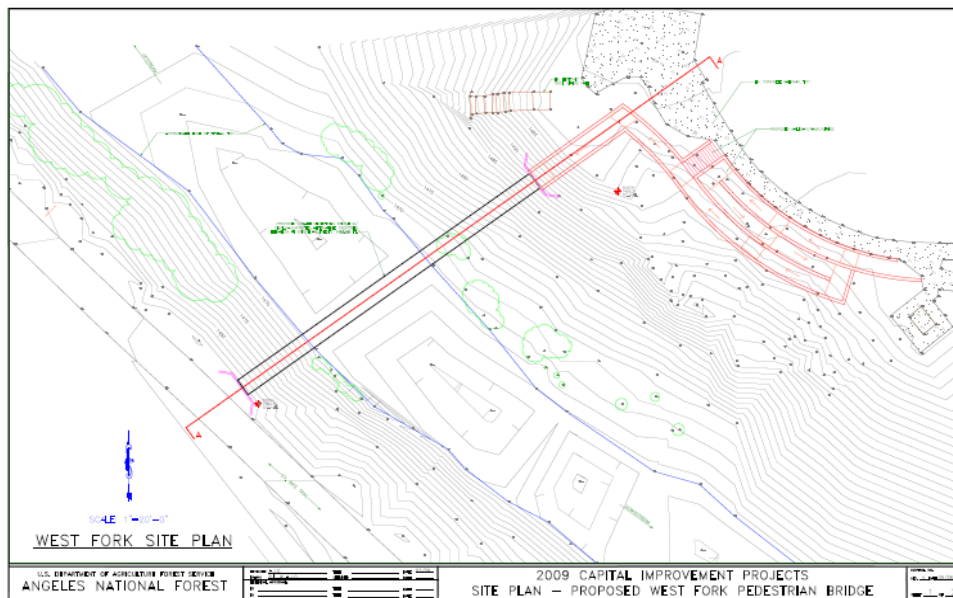


Fig. 6 Site plan and proposed bridge alignment for the site provided by the U.S. Forest Service

4.2.1 Quadra Bridge

The winning design for this project site was a 140 ft span bridge nicknamed Quadra Bridge. The design team addressed ADA requirements by providing a sufficiently long winding walkway to accommodate wheelchairs, sloping at 5%, the maximum allowed for a walkway that did not require intermediate landings. The portion of the walkway crossing the river was suspended from a 3D four-leg frame formed by the edges of the square pyramid. The two legs on each side of the river were joined together by steel structural tubing and, under the bridge deck, a chevron brace was provided as part of the lateral load resisting system. The 1/4"=1-0" scale model of the bridge is shown in Figure 7.



Fig. 7 Quadra Bridge 1/4"=1'-0" scale model

This shape of the bridge support structure provided an aesthetically pleasing design and accommodated a very effective structural system. The perspective shows the bridge in the site context, including the access to the hiking trail from the day-use site and the aesthetics of the design (Figure 8).



Fig 8 Quadra Bridge Rendering (1st Place)
Architects: Maro Asipyan, Matthew Terry,
Engineers: Christian Hains, Francisco Perez,
Bryan Strege. Original Design Concept by Mathew Terry.

The students also constructed a 1/2"=1'-0" scale model of the pyramid frame, shown in Figure 9 (while students typically constructed 1'=1'-0" details of the bridge, in this case it was determined that it made more sense to construct the entire frame at 1/2"=1'-0"). The legs of the pyramid structure were specified as glulam girders built from naturally decay-resistant species. The bridge deck was supported by coated steel cables connected to saddle straps wrapped around continuous wood

girders and the deck assembly; the girders also acted as stiffening beams for uplift loading. Stainless steel structural tubing was used to connect the legs of the pyramid. The two-leg frames were intended to be constructed on each bank of the river and joined together to form the apex of the pyramid. The design of walkways leading to and from the bridge used concrete supports spaced along the river bank to accommodate the girder and decking assembly. The project design criteria was: LL=80 psf, Wind Load, 120 mph (3sec gust) wind, Exposure C and Seismic

Loading based on USGS Hazard Map for this location and on geological information provided by the U.S. Forest Service. These design criteria were used by all teams for their bridge designs.



Fig. 9 Quadra Bridge 1/2"=1'-0" scale model showing support and apex connection

The SAP structural model of the bridge showing the layout of the main load resisting system and the distribution of

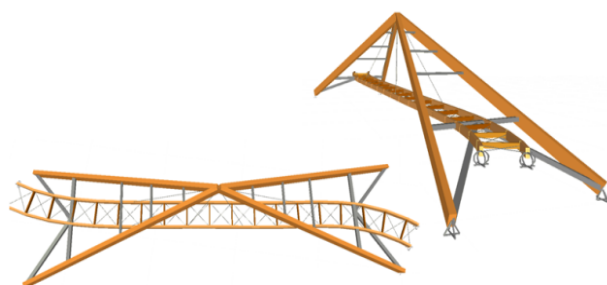


Fig. 9 SAP 3D Rendered Structural Model

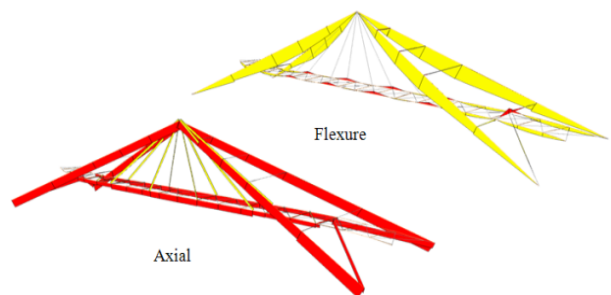


Fig. 11 SAP Structural Model Axial Load (in red) and Bending Moment (in yellow) Diagram

axial loads and bending moments throughout the bridge's main force resisting system due to vertical loading are shown in Figure 10 and Figure 11, respectively. The



Fig. 10 Connection at the apex of the pyramid frame: engineering drawing, top view and rendering of the elevation,

vertical loading are shown in Figure 10 and Figure 11, respectively. The connection at the apex of the pyramid was designed to accommodate the construction sequence, structural requirements and also to be an aesthetically pleasing element of the bridge. The renderings shown in Figure 12 are the side view, top view and

the conceptual representation of the cable to plate connection.

The assembly of the bridge deck support connection consisted of a structural steel tube at deck level that resisted the compression load generated by sloped cables and a combination of steel rods and steel plates wrapping around the bottom of the beams resisting tension loads. The conceptual engineering detail of this connection is shown in Figure 13.

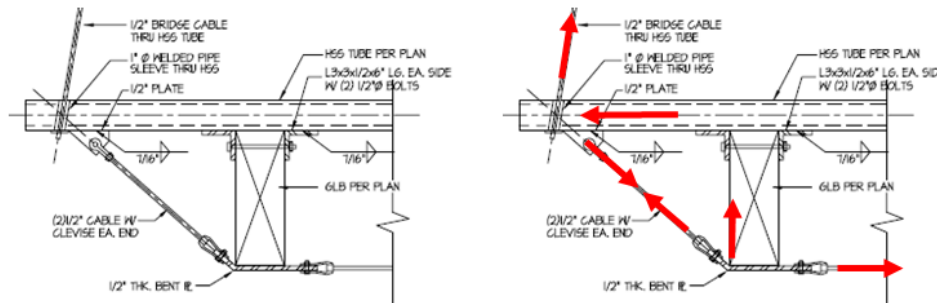


Fig.11 Bridge Deck Assembly saddle strap support conceptual connection detail and force diagram

This project earned the highest scores from the professional panel as well as from the faculty. It addressed in a simple and effective way the challenging architectural and engineering constraints of the project.

4.3 Winter 2012: Angeles National Forest, East Fork, San Gabriel River



Fig.12 Los Angeles Forest, East Fork, San Gabriel River, Bridge to Nowhere trail.

This project site was also identified by the U.S. Forest Service as needing a bridge. It was located along a very popular hiking trail called the Bridge to Nowhere (the trail terminates in a bridge designed as a link in a roadway that was not completed), where the U.S. Forest Service wanted an alternative to having hikers cross the river by jumping on rocks and logs. The proposed new bridge had to be visually appealing and contribute to the trail experience. The U.S. Forest Service did not require the students to design the bridge above the minimum flood level, but one important constraint was the ability to deliver materials to the

site. The available access was either by foot or helicopter delivery. Some of the photos of the site taken by students during the site visit are shown in Figure 14. A site plan was not available for this project, so students performed their own survey of the site, prepared a site plan and constructed a $\frac{1}{4}'' = 1'-0''$ scale site model. The U.S. Forest Service did not specify a fixed bridge location, thus allowing the students significant flexibility in setting their bridge. As a result, the bridge spans varied from 45 – 75 ft. Eleven designs were proposed during the preliminary phase of the project and five designs were selected for the final phase of the class. The designs were nicknamed and are referred to here by these names: (1) Truss Bridge, (2) The Crossing, (3) Knee Brace Bridge, (4) Arco Iris and (5) No Where Bridge. The winning design, Truss Bridge, is presented here. The design criteria were similar to the previous year's project: LL=80 psf, Wind Load 120 mph wind, Exposure C, Seismic Loading based on USGS Hazard Maps and latest ASCE 7.

4.3.1 Truss Bridge

The Truss Bridge was the winning design for this project. The bridge spanned 65-ft and featured a space truss using wood members for web members and the top chord and steel cables and rods for the bottom chord. The top chord also acted as a stiffening beam designed to resist uplift loading. The renderings of the bridge are shown in Figure 15.



Fig.13 Truss Bridge (1st Place) Architects: Richard Delarosa, Candice Myers, Harold Ornelas, Leo Rodriguez, Johnny Tran; Engineers: Kun Chang, Henry Chi, Huong Vu. Original Design Concept by Harold Ornelas

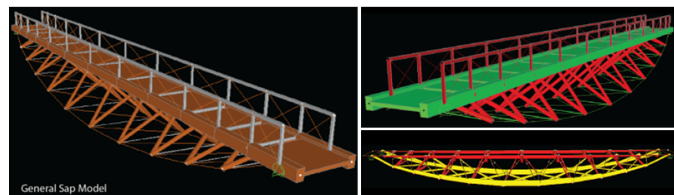


Fig. 14 Structural SAP Model and Vertical Loads Axial Load Diagram

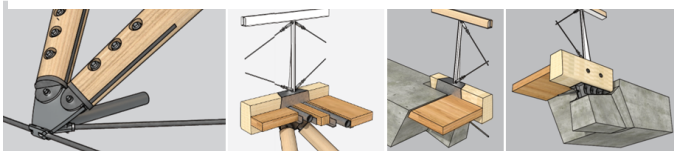


Fig.15 Connection details: truss web bottom connection and top connection, support top view and bottom view.

The bridge design used the curvature of the bottom chord to provide an optimized truss design and to provide more attractive connections at the support. The structural analysis of the bridge was performed using SAP analysis. The engineering students created a structural model of the bridge using frame elements and analyzed the structural model for dead, live, seismic and wind loads. The SAP model and an axial force diagram under vertical load are shown in Figure 16.

The detailing of the connections was important from both the architectural and structural perspective. Selected connections developed for this design are shown in Figure 17.

The students also built a $3'' = 1'-0''$ model of a section of the truss. The large scale of the model allowed students to experience some of the construction issues they would encounter in actually building the bridge and to address these as well as cost effectiveness. The image in Figure 18 shows the detail of the truss web members' connection to the top chord of the truss.



Fig. 16 Truss Bridge 3"=1'-0"scale model detail

5. Discussion, Conclusion and Acknowledgements

The student work presented in this paper demonstrates that collaboration between architects and engineers can produce aesthetically pleasing designs without sacrificing structural performance or cost effectiveness and constructability of the project. The use of pedestrian timber bridges as the class design topic, the progressive competition format and the involvement of the architectural and engineering professionals creates a truly inspirational learning environment full of creativity and an impressive student work ethic. The students were all highly motivated by the competitive nature of the project and devoted significant energies to delivering high quality work.

The AE interdisciplinary course provides a unique opportunity for architecture and engineering students to experience design collaboration in an educational setting. The course was highly rated by students and practicing professionals serving on the review panel. The course allowed engineering students to develop an understanding and appreciation of the aesthetics of design, to explore their creative side and learn to collaborate in developing and designing structural systems to accommodate architectural forms. The architectural students learned to develop a better understanding of the impact of structural requirements on their designs and to collaborate with engineers in developing forms that are conducive to constructible and economical designs.

The use of the studio format for engineering education is an excellent mechanism for developing many skills the industry desires in engineering graduates. These include creativity, collaboration, oral and written communication skills and the ability to understand the language and the needs of another discipline.

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