Session 3253

Bridge to the Future: the Freshmen Capstone Design Bridge Project at Union College

F. Andrew Wolfe, Christine C. Laplante
Department of Civil Engineering, Union College

I. Introduction

Union College is a small, 2000 student, undergraduate liberal arts and engineering college located in Schenectady, NY. The Engineering Division with an enrollment of approximately 400 students consists of four departments: civil engineering, electrical engineering, mechanical engineering, and computer science. In 1995, Union College was awarded a grant from General Electric to revise the freshmen and sophomore curriculums to provide a common engineering background for all engineering students. The freshmen year was redesigned to give students an overview of the different engineering and science disciplines and a computer language. The first trimester focused on giving the students a knowledge of engines and foundations. The second trimester was broken into six modules: C++, computer systems engineering, circuits, instrumentation, engines, and statics. With this background the students were then asked to chose a Capstone Design Project from three alternatives. The three projects were: build a steam engine, build and instrument a weather station, or design and build a truss bridge. Thirty-four students, approximately half the freshmen engineering class, chose to design and build a truss bridge. The bridge was to be donated to the City of Schenectady and erected in Vale Park as part of a trail system.

This paper explores the teaching process used to provide the students with the necessary knowledge to design and build a thirty foot truss bridge.

II. Course Overview

Union College operates on the trimester system. This gave the class 10 weeks to learn about trusses, design a truss, and then build and erect it on site. The course was divided into three parts. The first four weeks were used for teaching and labs. The next two weeks were used for design and model building culminating in a presentation before the Vale Park Task Force. The last four weeks were designated for building the bridge which included footings and site work on the trails.

A. Lectures

Lectures were held for two hours once a week. During lecture we concentrated on developing a design methodology which the students could use in designing a bridge. The lectures were team taught with each professor responsible for a part of each lecture. During lectures it was common for both professors to add to the other's lecture material with antedotal examples. Lecture material consisted of Statics material - particle equilibrium, forces and moments, method of joints, method of section, moment of inertia; Strength of Materials - stress, section modulus, loading diagrams, and AASHTO standards for truss bridges; and Economics - estimating bridge costs. The lectures did not cover bridge connections which were designed by Professor LaPlante once the final bridge truss design was determined. This allowed the students to concentrate on a truss design without connection concerns.

B. Laboratories

There were three labs used during the first four weeks to strengthen the lecture material. The first two labs were hands-on, while the third involved gathering data by observation. Lab 1 examined deflection in a 2" x 4" wood beam due to loads applied at the center, one-third and two-third points along the beam length. It also looked at foundation uplift due to loading. Lab 2 looked at geosynthetics and soils, compaction and holding ability. Lab 3 looked at connections and connectors. Screws, bolts, and nails were tested in specimens using a universal testing machine. There were four one and one-half hour lab sections for the class. This allowed all the students to have an active role in each experiment. As with the rest of the course, the hands on aspect of the labs was used to get the students used to handling the materials which would be used to build the bridge.

1. Lab 1

In this lab students used the setups shown in Figure 1 to determine the deflection of wooden beams loaded with concrete blocks. The blocks were weighed and then placed on the beam. Each beam was tested three times, at the midpoint and at each of the third points. Deflection was recorded by measuring the distance from the floor to the beam at the mid point and at the third points. Since both setups used two 2x4s each 2x4 was measured for deflection after each loading. This allowed the students to see that the beams were not homogeneous material, that composition, knots and wood grain played a part in the stiffness of the beam. The beam was loaded in both the major and minor axes so that the students could see how the moment of inertia played a role in the deflection. As a final exercise Professor Wolfe stood at the midpoint of the beams on their minor axis. Students then stood on the ends of the beams over the supports. The students found that they could not counter the moment generated by Professor Wolfe. The students were able to determine that to counter the moment they had to move the supports towards the middle of the beam. This demonstrated moment and uplift to the students. This became important when the foundations were designed. The students had to look at both settling and uplift in the foundation design. This lab demonstrated deflection, moment and the variation in strength of wood due to growth conditions.

2. Lab 2

In this lab students learned about geosynthetic use and placement, and soil compaction. The setup for this lab is shown in Figure 2. The purpose of this lab was to have the students determine how to support seventy pounds on a piece of geosynthetics stretched between two boxes filled with soil. The students first used sand as the fill material in the boxes. The sand

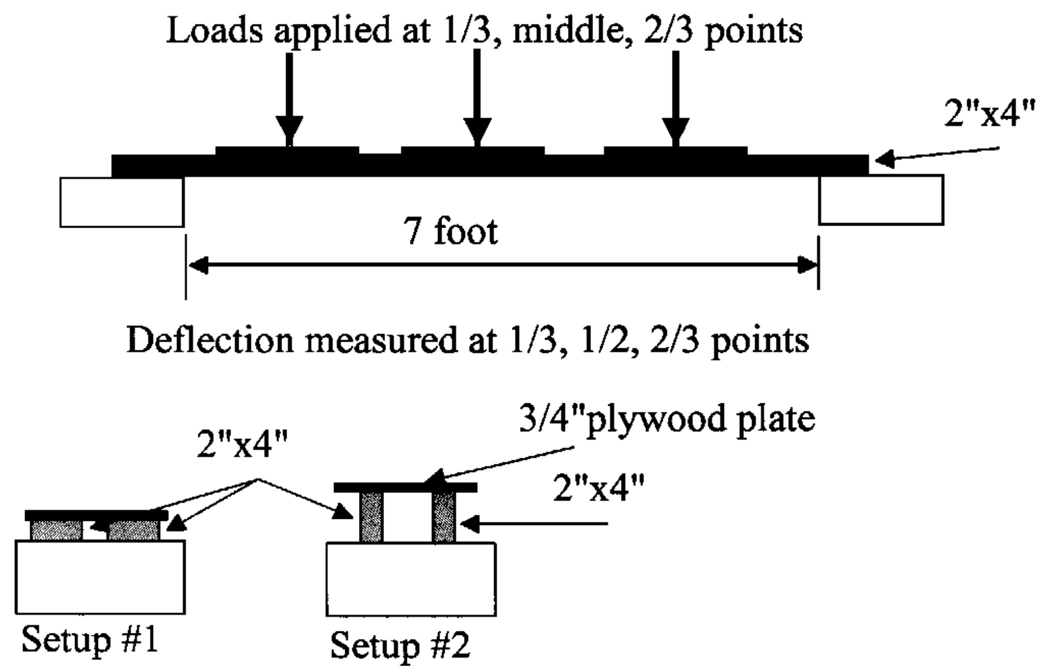


Figure 1. Laboratory One Set-Up

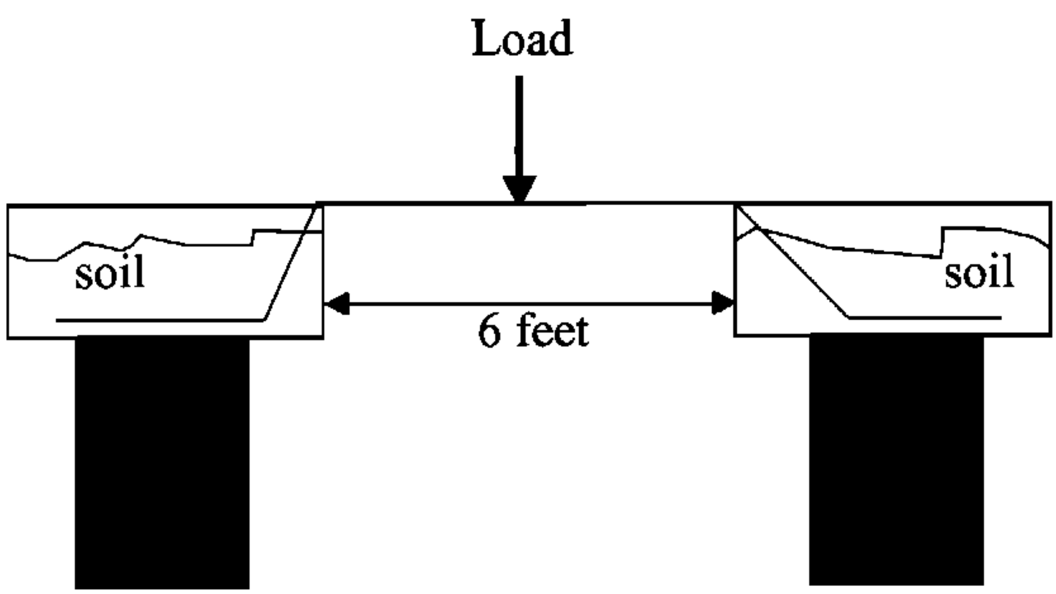


Figure 2. Laboratory Two Set-Up

had a low resistance to pull out of the geosynthetic. Next the students used a silty - clay material to anchor the geosynthetic. They packed the material above and below the geosynthetic. This setup supported the seventy pound weight. The geosynthetic was then loaded to pullout. It was possible to see the slip plane on the soil which gave the students a better understanding of how the geosynthetics worked. This lab gave the students a knowledge of soil compaction and how geosynthetics work.

3. Lab 3

This lab demonstrated the concepts of shear and connector strength using different wood orientation and different types of connectors. Specimens were made up prior to the lab. Two sets of specimens were made up, one set with the wood grain in the members parallel and one perpendicular. Each set of specimens contained a bolted connection made of 2 - ¼ inch carriage bolts with washers, a screwed connection using eight no. 8 – 2 ½ " long screws, and a nailed connection using eight 8 penny - 2 ½" long nails. See Figure 3 for the specimen setups. The specimens were tested in compression using a universal testing machine. In addition a pressure treated 4 x 4 was placed in compression along its axis until failure. From this lab students learned about factors of safety, the failure state of the connection, wood failure, pullout, or connection shear. The four lab sections were able to compare their results and calculate the range of stress values for the 4"x4" beam.

With the knowledge gained from the lectures and the lab experiments the students were now ready to undertake the design of the bridge. By using building materials in the labs, the students gained a knowledge of how the bridge materials would work. The hands on experience allowed the students to gain more experience than they would have with pre-made specimens and setups.

III. Architectural Model Development

The students were asked to utilize the knowledge they obtained in the class lectures to develop a scale model of a truss bridge using balsa wood. The students were placed in groups consisting of three to five individuals. Each group was responsible for the truss design, material list, economic analysis, and a diorama consisting of the actual topographical layout of the bridge site. As stated previously the students were not responsible for the bridge connection design. The bridge designs followed the AASHTO standards for pedestrian bridge design[1] and OSHA safety standards.

Each group was given the code requirements for use in the development of their design loads. The groups then had to design their bridge using the method of joints and/or the method of sections to obtain the member forces. They converted the member forces into stresses and sized the members accordingly. The code requirements included an 4070 Pa (85 psf) deck loading and a 1676 Pa (35 psf) lateral loading. The students utilized CMETRUSS[2] to design trusses as well as check the chosen wood sizes, applied stresses and deflections.

Students were encouraged to utilize their imagination and artistic ability to develop an aesthetically pleasing bridge. However, they were also required to maintain cost consciousness.

Their economic analyses included the actual cost of the materials to build the bridge plus the cost to maintain the bridge for ten years. The students used lumber yard flyers and visits to

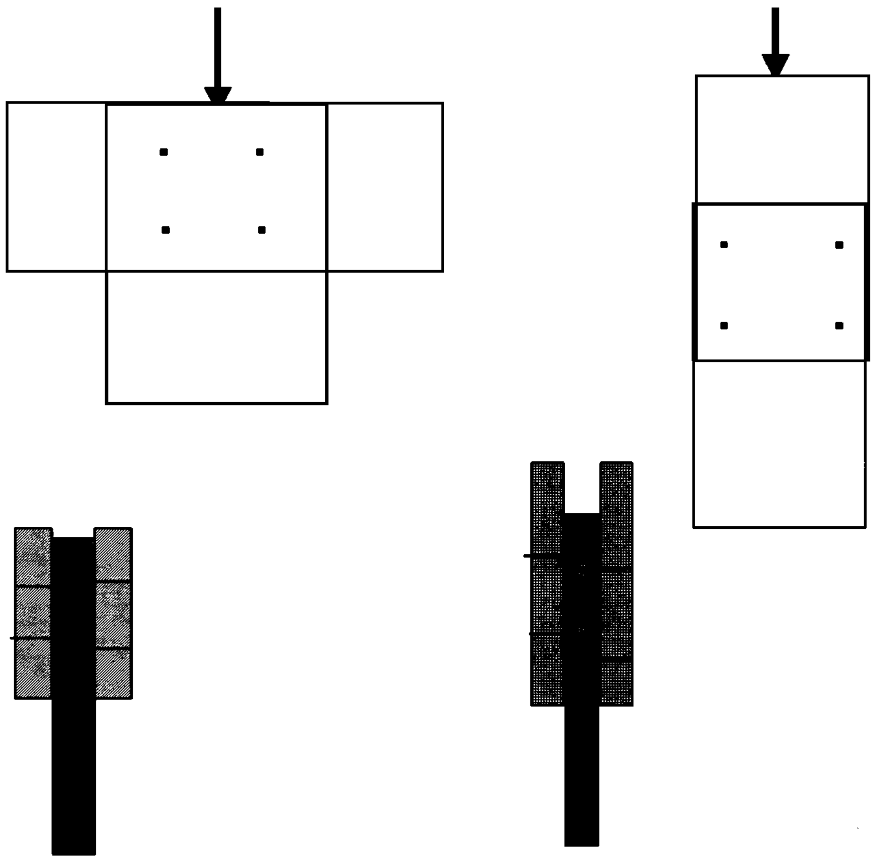


Figure 3. Laboratory Three Set-Up

lumber yards to determine the costs of their materials. The labor costs were not considered since Union College students were building the bridge and the labor was considered a donation. Several of the dioramas are pictured in Figure 4.

The location of the proposed bridge was in a wooded park/ cemetery. Vandalism in the park was common. The students needed to address vandalism issues such as graffiti and the actual cutting or burning of the bridge. The groups designed their bridges with redundant members and evaluated various paint products to minimize vandalism. The students found that some of their suggestions were too costly and that to design for every possible case of vandalism was impossible. They discovered that their solutions were not fool proof and they were expensive. They learned a good lesson about civil engineering design. They learned that there must be a trade-off between cost effectiveness and design, when designing for every possible case of vandalism, and this trade-off is trust in our society.

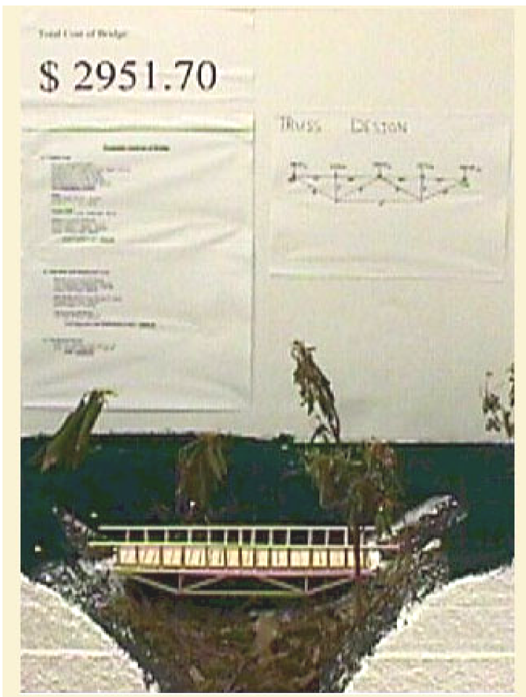
IV. Public Forum Presentation

As part of the new freshmen course curriculum the students were required to develop and perform several presentations. This allowed the students to develop their public speaking skills and proper presentation skills. On this project the students were required to present their dioramas to a public forum consisting of the Vale Park Task Force, Union College faculty, the Dean of Engineering and other students. This type of presentation was different from what the students were used to. By running the presentation as a poster session we attempted to more closely simulate an actual design competition for the bridge. The task force consisted of lay people with minimal civil engineering knowledge and a licensed profession civil engineer (PE) who specialized in structural design. The Vale Park Task Force was given the task of selecting the bridge they would like built in the Park. Their concerns were yearly maintenance cost and safety issues.

Initially the task force spent about fifteen minutes reviewing each display and questioning the students. After the display review each group gave a five minute presentation on their bridge design and maintenance costs. After the presentations, the individual student groups addressed questions. Safety became a major concern with the task force. Several of the bridge designs had structures, which extended out away from the bridge for use in lateral bracing (Figure 5). These supports were needed to meet the 1676 Pa (35 psf) lateral load code requirement. The task force was concerned that children would use these structures to swing and play on. These concerns affected their selection of the winning bridge. The task force selected the bridge shown in Figure 4c. They felt that this bridge was the most esthetically pleasing and safe. They also selected an alternative or runner up in case the cost of the connections of the chosen bridge was too expensive. The bowed truss shape of the winning bridge required a large number of connections, increasing the material costs and construction difficulty. The runner up bridge, an under- truss design, was chosen. This bridge was less costly and easier to construct.

The PE on the task force expressed concerns regarding the adequacy of all designs when pedestrian loaded. The students assured him that each design was to AASHTO standards and OSHA safety requirements. Also, the bridge selected will be re-checked and if necessary redesigned to ensure adherence to these codes mentioned. Another concern of the Engineer was handrails. Some of the bridges were using the truss structure as the handrail to save on material costs; however, the trusses did not fully meet the OSHA handrail requirements. OSHA required a maximum rail opening of 4”. The spacing on the truss members was much larger. Again, another valuable engineering design issue was learned by the students. That is, safety must be the number one consideration and cost second.

(a)



(b)

(c)

Figure 4. Student Bridge Dioramas

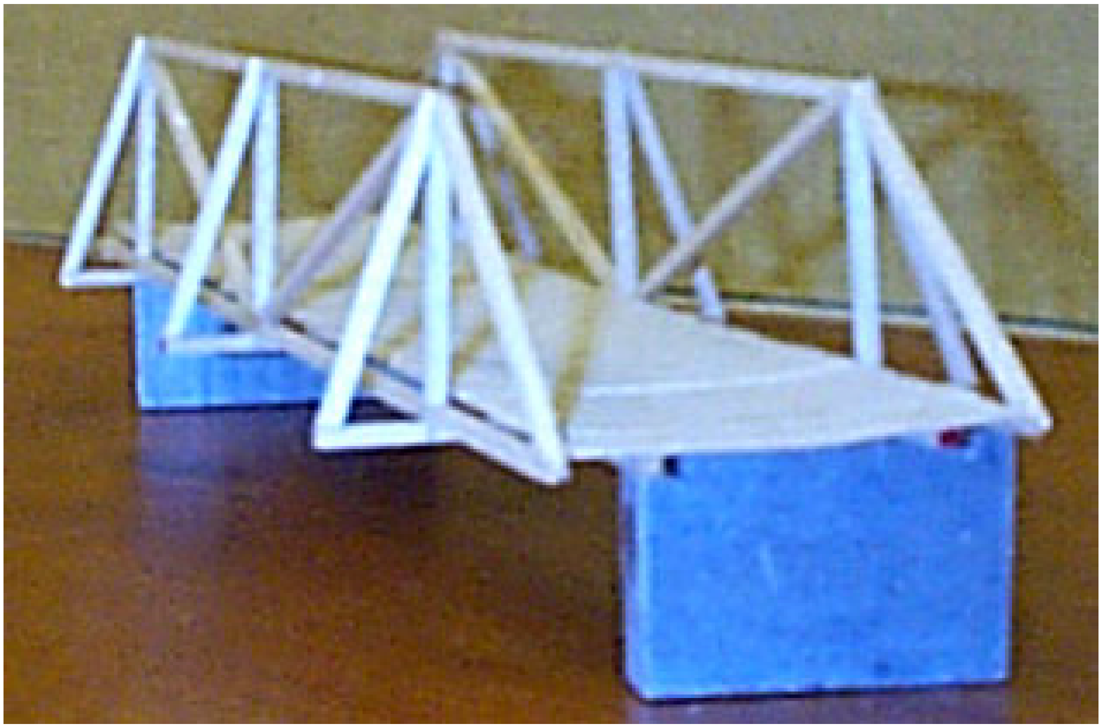


Figure 5. Student Bridge with lateral bracing.

The presentation gave the students a chance to see how the selection process would work on a construction project. It also showed them that the public does not always have the same concerns as the engineer and designer. The engineer has to be ready for unexpected questions and concerns and needs to be able to address the issues which are raised.

V. Construction Phase

As a help to the students a field trip to a local truss shop and lumber yard was arranged. The students were shown all kinds of fasteners, woods (including glue-lams), sonotubes, and truss types. This was done to show the students that there was a wide variety of truss types and how truss members are connected. It also showed students that there are many materials available for construction.

Prior to construction, the bridge was analyzed and the connections were designed by Professor LaPlante. Construction drawings and templates were developed by the laboratory technician for the truss design and the connections. The foundation was designed by the students with the assistance of Prof. LaPlante. Telephone poles were chosen for the foundation. They were to be used as piles driven into the ground.

The construction of the bridge was performed in the following three phases: site- work, foundation installation and bridge construction. All the construction was performed by hand (i.e. no cranes or heavy equipment was used). The site work phase consisted of clearing and grubbing. Large trees where removed and cut for use in the foot path development. Foot paths were cleared and wood steps were installed along the trail to and from the bridge. The next stage was the foundation installation. The telephone poles were delivered to the site and hand-driven into the proper locations. The poles were placed in four foot deep holes dug by the students and pounded into place by the students using an additional pole until the poles hit refusal or showed no additional movement after approximately 100 blows. Bearing beams were bolted in place at the top of the poles allowing for placement of the trusses and deck structure.

The bridge construction was initially performed in the school laboratory. The students were divided into three groups. Each group had to work during one two hour block per week. This was done for two reasons. The first was a constraint on space, 33 people could not fit into and work on the truss in the laboratory. the second was to get all students deeply involved in the truss construction. With groups of ten to twelve students it was easy to keep everybody working. Four identical trusses were built. The trusses were doubled for protection against vandalism. Base plates were installed with lag bolts which the students drilled and hammered into place. For some of the students this was the first time they had ever used a power drill. Figure 6 shows the completed construction of the trusses and the start of the bridge deck stringers and railings. All the wood for the decking and railings was cut in the lab. Students performed all the measurements and markings for the cuts but were not allowed to actually cut the members due to College rules regarding the use of power saws. The bridge was built in four parts (i.e. 2 double trusses and 2 deck/railing sections) and put together at the site. The students were faced with two challenging issues: First, how to get the large bridge sections to the site? And second, how to put these heavy sections in place with out the use of a crane. The trusses weighed over 300 hundred pounds. Figure 7 shows the students rigging the trusses in the laboratory and feeding them out to a flat bed truck. Figure 8 shows the students putting the trusses in place down the slope and onto the foundation. Once the trusses were in place the deck and railings were secured (Figure 9). The truss construction was completed in three weeks. Actual erection of the bridge took two days. On the first day the trusses and deck frame were moved onto the site and setup. On the second day the approaches, decking, railing, cross bracing, and site work were completed. Figure 10 is a picture of the completed under-truss bridge.

Throughout the entire construction phase the students were able to observe the different individuals (i.e. designer, fabricator and contractor) involved in the actual construction of a civil engineering project. The two professors and the laboratory technician each played a different role. Conflicts between design and fabrication arouse immediately with the development of the base plates. As typically occurs in real life, the designer wanted plates which were costly and difficult to machine. Compromises had to be made; however safety and design requirements were not compromised. Students observed the exchanges between the designer and fabricator learning that compromise is a key for success. They often asked questions about the conflicting

(a)

(b)

Figure 6. Laboratory Construction Phase

opinions and how the conflicts were resolved. As construction continued, design changes occurred and conflicts arouse between the designer and the contractor. The contractor often changed connection details for ease of construction. This resulted in design changes and reevaluations. Compromises again were made. Students were told that contractors specialize in the means and methods of construction and at times a designer's design may not be constructed by conventional means, or may just be too costly to construct. Students realized that constructability reviews during the design phase of engineering projects are necessary and they should be performed by someone knowledgable in construction techniques.

VI Conclusion

This project was successfully completed on Saturday, June 6,1998 with a ribbon cutting ceremony. During construction and erection all the students learned how to operate power tools, drive nails, and deal with construction problems. This project made the students more aware of how a bridge is built and the value of communication between all parties during the design and construction phase. There were two major drawbacks of the project. One was that the students were too interested in the bridge and allowed other coursework to slip so that they could spend extra time working on construction. The other was a major time commitment from the professors and laboratory technician. All connection design and fabrication, site surveying, materials gathering, detail work and problem resolution (permits, money) needed to be handled so that the students could concentrate on building.

Overall the students learned many lessons which will help them as they advance through their college courses. These students have completed Mechanics I (Statics and Dynamics) and felt that the bridge gave them an advantage in understanding the material. This should hold true for all their sophomore engineering courses. The students also became more spacially aware. In this era of computer games, it becomes harder to explain how structures are built because the students do not have the experience of building. This project gave them a chance to build and put together a structure, develop the spacial relations of the truss, deck frame, decking and rails, and the satisfaction of completing a large project in four weeks.

For these students the bridge is a piece of their college experience which will remain with them for life. Many of them returned from summer break and went to the bridge to see how well it was holding up. In the spring of 1999, the class will paint the bridge.

(a)

(b)

Figure 7. Moving of the Bridge to Vale Park

(a)

(b)

Figure 8. Placement of Bridge Trusses in the Field

(a)

(b)

Figure 9. Placement of the Bridge Deck and Railings

Figure 10. Union College's Bridge to the Future

Bibliography
1. American Association of State Highway and Transportation Officials (AASHTO), Guide Specifications for Design of Pedestrian Bridges, AASHTO, pp.21, (1997).
2. URL: http://www.dean.usma.edu/cme/civilsoft.htm; CME TRUSS ver. 2.1, West Point, NY (1994).

Acknowledgements
The authors would like to thank the following individuals for all their help and efforts to make the bridge project such a success: Shamir Pasha-laboratory technician, Bell Atlantic- donation and deliverance of the telephone poles for the foundation, Vale Park Task Force and finally many thanks to the freshmen bridge design class- class of 2001.