A Bridge to High-School Girls: A Versatile Recruiting Tool

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Abstract:

High school girls are bombarded by counselors and others, encouraging them to consider careers in science and engineering. We feel that encouragement is of greatest value with a sampling of the career; therefore we designed and built a 16-foot long wood and steel bridge to enhance a recent recruitment session. The girls in the session were introduced to structural topics, then they assembled the bridge and were able to cross it at the completion of the session. The bridge was the focus of the session, in lecture as well as hands-on, as an example of the types of work performed by engineering technologists. The bridge proved itself a suitable introduction and recruiting example, and indeed the girls were excited by the project and a possible career in engineering technology. At the end of the session the bridge was disassembled and stored for future use. The material cost for the bridge was small, although significant time was spent in fabrication. The bridge can be readied for other recruiting sessions in less than thirty minutes.

A set of alternative uses for the same bridge has been identified, most unrelated to recruiting, but significant enough in utility to suggest that such a bridge should be constructed even if never used for recruiting. This project arose from a Mechanical Engineering Technology program, and this paper is specific to an MET program. Identified non-recruiting uses are varied enough to be broadly applicable to many programs in similar ways. The bridge has been used for demonstrations and assignments in statics, instrumentation, and computer courses, and may be used in strength of materials and manufacturing courses. The bridge is a physical object, so unlike textbook examples, the effect of manufacturing variations can be visibly demonstrated. The bridge is also large enough that teamwork is required to handle the parts and to physically assemble the bridge. The number of parts in the bridge can also require teamwork for assignments in design, manufacture, or analysis.

The specifications and chosen design for the bridge are detailed in this paper. An outline of the recruiting session presentation is provided with comments based on our experience with this presentation. Suggestions are provided for others who desire a similar recruiting object other than a bridge. The versatility of this bridge for classroom demonstrations, assignments, and projects is tremendous, and a selection of possible uses are described in this paper.

I. Introduction:

In an effort to stimulate the interest of middle school girls in technical fields, the Center for Corporate and Adult Learning (CCAL) at Penn State Erie, The Behrend College began an outreach program in 1997 called Math Options. Through hands-on workshops, encouragement, role modeling and mentoring, the program stresses the study of math as a foundation for future college majors and careers.

For a week-long Math Options camp during the summer of 2000, the first author was approached by CCAL to develop a workshop to introduce one aspect of engineering and engineering technology to middle school girls. The topic of the workshop was chosen as “structures” because structures are common in everyday life, yet are generally not understood by the public. The two-hour workshop consisted of two parts: a one-hour discussion of building and bridge structural elements, loads, and stresses, and a one-hour long hands-on session in which the girls erected a 16-foot long wood and steel bridge which was designed and fabricated by the authors. A full-scale bridge was chosen for the hands-on session to create an exciting and memorable engineering experience for the participants. Watching the girls play on the finished bridge left little doubt that it was an exciting and memorable experience for them. This was confirmed by thank-you letters received from organizers of the overall program.

The bridge was fabricated from wood and steel purchased locally for less than $300. Even with a complete metal shop available, a great deal of effort went into the fabrication of the bridge elements. Since the bridge is versatile as both a recruiting tool and teaching aid, the effort is deemed to have been worthwhile.

II. Bridge Specifications:

To make a big impression, the bridge had to be large. Yet, to be assembled by young girls, it had to be lightweight. To store it, volume was an issue. The bridge also had to be strong enough to support a number of girls and adults walking and jumping across it. Lastly, the bridge had to be inexpensive and simple enough to be built.

A sixteen foot span was selected so that the deck could be made from a single sheet of plywood. Each of the 2-foot by 4-foot deck panels has a manageable weight. The height of the deck was set at 5 feet so that it would be at or above eye level of most of the girls. Wood abutments were constructed to support the bridge at this height. The height of each of the trusses is 3 feet which provides a two foot clearance between the bridge and the floor. The worst case load was assumed to be a large individual jumping at mid-span. Using a conservative design factor, a 2800 pound load at the mid-span of the bridge was used for design. Each panel of the truss is 4 feet long and 3 feet high so that the diagonals would be 5 feet from pin center to pin center. These dimensions were chosen to match materials on hand, and should be adjusted as required by another bridge builder.

The bridge was fabricated from wood and steel. Wood was a chosen because it is affordable, commonly available, strong enough, and easily machined. The compression members and those members experiencing bending and compression were made of wood. Tension members and those members experiencing stress reversal due to the moving load were fabricated from steel because of its high strength and relative light weight. The steel tension members were fashioned into eyebars from steel stock in accordance with the AISC Manual for Steel Construction[1]. Other steel members were fashioned from available steel tubing and purchased steel bars. Sheet metal gussets and welded brackets pin the wood truss members to each other and to the steel members. Grade 5 bolts act as pins at each of the joints connecting the steel members. Steel conduit was used to make two sets of cross-bracing between the trusses to add stability to the assembled bridge structure.

The authors fabricated the bridge on campus in a machine shop used for teaching machine shop practices to mechanical engineering technology students. The design, solid modeling, detailing and fabrication of the bridge approached 400 man-hours. Because some of the materials used were in stock, the total cost for the bridge was less than $300.

III. Recruiting Session:

The presentation began with a discussion of the fields of study in engineering and engineering technology that can lead to careers as structural designers. These included civil, architectural, and mechanical engineering and engineering technology.

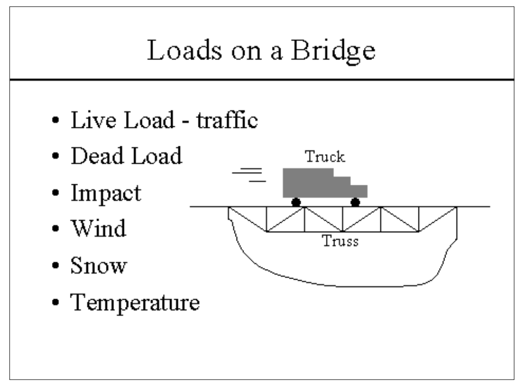

Figure 1

A discussion of the types of loads exerted on buildings and bridges followed. These included dead loads, live loads mandated by building codes, wind, snow, earthquake, thermal and impact loads, Figure 1. This discussion introduced the concepts of codes as instruments of public safety. Wood, steel and concrete were discussed as building materials for structures. The girls were shown the design codes for each of these materials as examples of the kinds of references structural designers use in design.

Structural elements came next. Beams, girders and columns were discussed along with bearing walls, footings, and trusses. The concept of load path was incorporated into this discussion. The girls were told how the weight of the presenter was distributed through the floor to a beam which loaded girders, which loaded columns and footings, which finally transferred the load to the ground. To the amusement of the audience, the second author then jumped up on a desk and exposed the roof structure of the building by removing several ceiling tiles. The girls were quite interested in seeing the structure that was opened to their view in this unorthodox manner.

The girls were next asked to stand and hold hands with a partner. They were asked to pull away from each other to experience the feeling of tension. In a similar manner, they were asked to push against one another to experience compression. This lesson was a precursor to the discussion of tension, compression, and moments, and how these concepts work together to cause a beam carry a load. Figures were used to illustrate how tensile and compressive stresses exist in a beam and that together, they form an internal moment to transmit a load to the ends of the beam. The concept of tension and compression in a beam was further illustrated by using the "Beam in a Box". The beam in a box is a collection of wood blocks held together by a chain. Nuts on threaded rods at the end of the chain are tightened to compress the blocks and put the chain in tension. Once the elements were sufficiently stressed and the assembly was set on blocks, the author stood on the newly created beam.

After the lecture session, the girls were taken to a hallway where the pieces of the bridge were pre-positioned. Verbal instructions were given to orient the trusses to the abutments, and the girls very quickly had the bridge assembled, Figure 2. We observed that the girls understood how the trusses, deck, and abutments were positioned and fastened with little instruction. Some instruction was required for the cross braces between the trusses and the handrail ropes. In ten minutes the girls had the bridge assembled and were ready to cross it.

Figure 2

As designed, the bridge is quite stiff yet some parts appear delicate and do not give confidence to people about to cross the bridge. When a faculty member climbs up onto the bridge, carefully walks across, then returns to the middle and jumps up and down, the viewers are reassured and ready to cross. The girls walked across, jumped on the bridge, went for additional trips, and were generally pleased with what they had seen and done. The sponsors and chaperones for the program also took trips across the bridge, which delighted the girls. Finally, the first author returned to the middle of the bridge and started to explain which members were in tension and which in compression. At this point the second author started removing the bolts from the zero force member in the center of one truss, Figure 3. The speaker made a big show of acting afraid that the bridge would collapse with him aboard which of course it did not, until the zero force member was completely free. We suspect that the discussion of zero force members will be remembered from this graphic demonstration.

Figure 3

After the demonstration, the handrail ropes, deck, and cross braces were removed and the bridge stored for future use. We would have liked to have the students assemble the trusses, but the complexity of the trusses and number of pieces take longer to assemble than would be useful for either recruiting or classroom demonstrations.

There were many favorable comments from participants and program staff regarding the bridge demonstration, Figure 4. They all know that they did not build the bridge, yet because they assembled and got to walk across it, the experience was memorable. We expect to offer a similar session in May 2001, probably adding additional hands-on activities related to structures. The written evaluations at the completion of the program were favorable, yet we have no data suggesting that even one girl changed her attitude or career plans as a direct result of this program.

IV. Non-Recruiting Uses


Figure 4

A summer section of statics was in process during the construction of the bridge. Computation of a selection of member forces, and examination of one truss, was incorporated into that course. Students in statics courses are called upon to compute forces in structures, usually with dimensions provided in the problems, but do not actually consider the large size of parts until presented with a physical system, such as this bridge, to analyze. Most statics texts show idealized joints in the structures in examples and problems; this bridge was an object lesson in how the ideal is realized in practice. A topic which is rarely covered in statics courses is the need for out-of-plane bracing to keep a structure stable. We have not incorporated stability computations into our statics courses, but this bridge is an easily understood demonstration of the need for such bracing. We showed the students the large lateral motion of the trusses from a small side load without the cross braces, and how stiff the truss became when the braces were installed. The completed bridge is now available to statics instructors with the suggestion that students be assigned to write a spreadsheet to compute the forces in all the members for a load at any position on the deck. Students more easily grasp that the load in a member changes as the load moves along the length of the structure when they can walk on the physical device.

For strength of materials courses, a bridge is a comprehensive example. The truss members contain straight tension members, compression members, shear pins, and members that are sometimes in tension and sometimes in compression. This bridge contains physical illustrations of each of these types of stress. The top chord of the trusses are wooden compression/bending members. The students may be directed to analyze the truss or individual members with the loads only at the joints to give pure tension or compression in the members until the course has progressed far enough to handle combined loading, and then the students assigned to analyze the structure with the loads between the joints. Unlike many textbook problems, the end connections on the bridge members are real and clearly different from the balance of the member. The instructor may direct the students to analyze both the member and its end fittings, and because the student has the physical model, should better understand the relationship between member and end detail. Because the load on a bridge may be placed at any location along the length of the bridge, assignments may be given for a single load but each student to perform the computations for a different position. As designed, only wood and steel members were used. In future semesters it is proposed to have students design replacement members of alternate shape or material to improve the strength or reduce the weight of the structure.

In a computer applications course, an attempt was made to make a solid model of the bridge with all dimensions parametric so they could be changed as desired. The solid model was linked to a spreadsheet where load and stress computations were performed to determine the required cross-section of each member and return to the solid model. The first author was able to do this, but in an independent study course the student was less successful. It is suspected that this assignment is more than a single student can handle and might work better with teams. Another possible assignments is to compute the deflection of the bridge, either by finite element analysis or by virtual work method, either of which may be accomplished by spreadsheet computations.

Strain gages were applied to two of the truss members by students in a measurements course. On each member, four strain gages were installed and wired in full Wheatstone bridge arrangements. Computations were made to determine the settings for strain indicators so that the displayed value would be the force in the members rather than the strain. When connected to the instruments, the varying forces in the two members is displayed as a person moves along the length of the bridge, and if connected to an oscilloscope, the impact performance of the members can be displayed. Students in the measurements class were intrigued by the potential for incorporating this technique in other equipment. We feel that this demonstration provoked a higher level of learning as indicated by students applying the concept beyond the specific example at hand. Measurement of the forces in the members for various loading cases would be more valuable if there were theoretical computations available for student comparison. Likewise, measurement of overall deflection would be possible, but would be better if comparison with theory were included.

Manufacture of the original parts for the bridge approximately half of the total project time, or about 200 man-hours. Construction of another bridge, or replacement parts for the first, would be ideal for a student manufacturing course since the parts are not extremely complex, yet are stressed at levels that require careful work. Bridge members require a variety of manufacturing methods on each part, so are appropriate for integrating several skills on a single part. The length between the pins in the truss members is important to having the parts fit together, but most of the other dimensions have plenty of tolerance so that inexperienced machinists should have minimal trouble with fabrication.

V. Conclusions:

We have found a bridge to be an excellent demonstration of engineering in general, and structural topics in particular, and is an injection of real life because it is available to touch and big enough it is clearly not a toy. This bridge has been used in a variety of courses, and has potential uses in others, limited only by the imagination of instructors. Another device having similar attributes could be used in many of the same ways and courses. If another device is chosen, it should be simple, familiar to the uninitiated, large enough for the customers to handle, and have moderate geometric tolerances for ease of manufacture and assembly.

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