Building Bridges: Computer-Aided Design as a Vehicle for Outreach to High School Students in the New Millennium

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I. Introduction

This paper describes the use of a computer-aided design (CAD) software package as a vehicle for outreach to high school students. Particularly, this research effort afforded pupils at a secondary school in central Pennsylvania the opportunity to participate in a program that was designed to accomplish the following:

- To stimulate interest in engineering and design.
- To provide the user with an opportunity to perform a legitimate structural design, based on a realistic set of design specifications and constraints.
- Provide participants with an opportunity to use the computer as a problem-solving tool.

II. The Computer-Aided Design Software Program

Called the *West Point Bridge Designer*, the software for this program was actually developed to support a nation-wide competition scheduled for November 2001. Using the 200th birthday of the United States Military Academy as a target of opportunity, the West Point "Bicentennial Engineering Design Contest" provides a computer based framework for designing bridges similar to the one depicted in Figure 1. Aimed at promoting math, science, and technology education in elementary and secondary schools, students in Kindergarten through 12th grade throughout the

Figure 1. Student Rendering of the Howe Truss Bridge from the *West Point Bridge Designer*.

United States working individually or in teams of two may compete for prizes that range from laptop computers to $15,000 scholarships. This future educational competition was developed with the following goals:

- Provide participants with an opportunity to learn about engineering through a realistic, hands-on design experience.
- Provide participants with an opportunity to use the computer as a problem-solving tool.
- Commemorate the Bicentennial of the U. S. Military Academy – the first school of engineering in the United States.
- Commemorate the 150th Anniversary of the American Society of Civil Engineers – the first national professional engineering society in the United States.

Although the *West Point Bridge Designer* software will ultimately serve as the linchpin for the contest later this fall, it is nevertheless available now as free, downloadable shareware from the West Point web site (http://bridgecontest.usma.edu). A newer version will be released at a later date to support the actual competition, but the current software is quite powerful and, for the young budding engineer, very interactive and enticing. The software effectively guides the user through the design of a truss-type highway bridge and includes – at an elemental level – all of the fundamental aspects of design as defined in the ABET accreditation criteria. The projects are based on real-world scenarios; they are open-ended, permitting many possible solutions; and they require formulation of problem-solving methodologies as well consideration of alternatives and economic concerns relating to the finished project. The final structure designed and optimized by the students must be a simply supported truss of a specified span length, a maximum height restriction, and minimum clearance over the high water level of the creek. Within these bounds the user has complete freedom to define the shape and configuration of the structure. The design must be capable of carrying its own weight and the weight of a standard AASHTO truck loading. The principle design objective is to minimize cost.

III. High School Outreach Methodology – Opening the Door to Engineering

The outreach methodology featured a bridge design contest limited to students in grades 9 through 12. The contest encompassed three sequential phases for execution (see Figure 2):

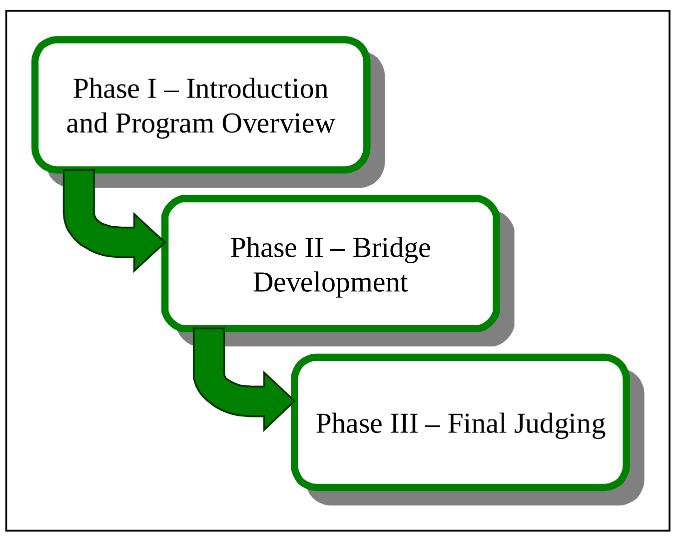

Figure 2. High School Contest Methodology.

Phase I – Introduction and Program Overview; **Phase II** – Bridge Development; and **Phase III** – Final Judging.

Phase I began appropriately with the High School principal with several follow-on meetings with interested science and math teachers. As an obvious prelude to the actual *West Point Bridge Designer* Contest in November 2001, guidance counselors also exhibited an interest and generally supported the effort. After these introductory sessions, school authorities granted access to the students to introduce the contest parameters and the *West Point Bridge Designer* software. Phase I included marketing

Figure 3. Excerpt from Bridge Design Contest Flyer.

initiatives to broaden the target audience. Flyers like the one shown in Figure 3 posted in school hallways, distributed directly to high school teachers, and placed on bulletin boards worked to generate interest and to encourage wider participation throughout the student body. Science clubs and veterans of the recently concluded High School Science Olympiad competition became an immediate target for the contest. Some academic courses also offered incentives to students in the form of extra credit for participation in the contest. Introduction to the software stimulated the students' intellectual curiosity about the design parameters employed by the computer. This prompted several group discussions dealing specifically with some of the more basic design fundamentals and their role is potentially optimizing a bridge design.

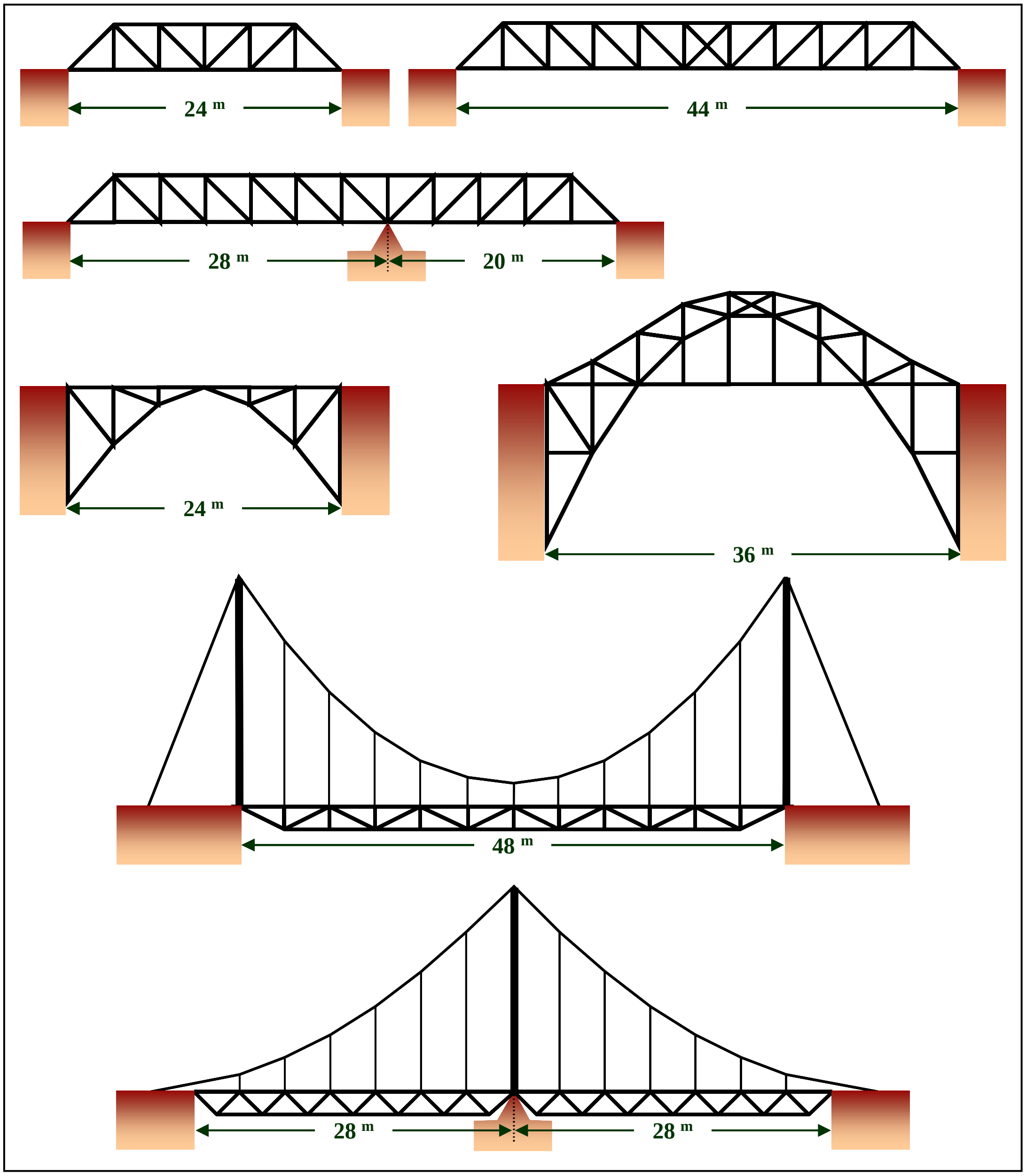

Figure 4. Initial Bridge Templates Employed by the Hugh School Students during the Bridge Design Competition.

Phase II focused on supporting student efforts as they began working either individually or in pairs to develop their bridge designs. The students were challenged to design bridges in all seven categories featuring a variety of bridge spans and configurations as shown in Figure 4. Additionally, the software provided templates for multiple variations in the types of trusses available for each bridge and span allowing for a total of 34 possible independent bridge initial designs. In each case, students experienced the engineering design process in a simplified but essentially the same manner that practicing civil engineers design real highway bridges. During each of the seven different design projects, students were presented with a requirement to design a steel truss bridge to carry a two-lane highway across a river. Each design carried a unique set of site conditions for consideration and followed a specific methodology:

- Students developed an initial bridge design by constructing a drawing on the computer screen usually based on a template provided by the software. The template typically provided guidance on location of truss joints or nodes and employed a generally acceptable default size for truss members that would produce a viable design.
- Once the first design attempt was completed, the student could direct the *West Point Bridge Designer* software to test the bridge and verify it was strong enough to carry the specified highway loads. The test includes a full-color animation showing a truck crossing the bridge. If the design is strong enough, the truck crosses it successfully; if not, the structure collapses.
- If the bridge collapses, the software automatically highlights the truss members that failed during the load test. The student can strengthen the bridge by changing the types of steel, adjusting the sizes of the structural components that make up the bridge, or by modifying the configuration of the bridge itself.
- Once the bridge successfully carries the loading without collapsing, students continue to refine the design to minimize cost while still ensuring that it can carry the specified loads.

The *West Point Bridge Designer* gives the student complete flexibility to create designs using any shape or configuration. Creating and improving designs was fast and easy so students ably experimented with many different alternative configurations as they worked toward the best possible solution to each of the seven categories of bridge design. In many cases, hundreds of design iterations were recorded before the student felt the design was complete and a high level of economy achieved. Further, their enthusiasm for engineering as a field was heightened as the process employed so closely paralleled that used by practicing civil engineers as they design real structures. In fact, the *West Point Bridge Designer* itself is quite similar to the computer-aided design (CAD) software used by practicing engineers, and served in the same way that CAD software helps them – by taking care of the heavy-duty mathematical calculations, so that they can concentrate on the creative part of the design process.

Phase III featured final judging of student submittals. Student designs were first checked to verify that they complied with program parameters and that the bridge was, in fact, sound. Victory was awarded based on the most economic designs. With each of the seven bridge categories, a standard template set by the computer produced an associated base cost that ultimately provided a yardstick to measure student efforts to optimize the cost of their bridge designs (See Table 1). Throughout the bridge design process, the software automatically tracks the total cost of the bridge as the design team worked to modify the bridge to optimize its economic worth. Students competed for "Best Designs" in each of the seven categories as well as for an overall "Grand Champion" for the lowest total cost for all seven categories. The success by the students in producing sound, economic designs was apparent as even average designs normally cut the *West Point Bridge Designer* base cost by nearly 50%. Due to space limitations and at the request of some of the students who wish to use their designs as a basis for competing in the nation-wide contest next Fall, examples of student bridges are not included with this article.

Table 1. Bridge Configurations and Associated Base Costs.

Bridge Type	Span	West Point Bridge Designer Base Costs
Single Span Truss	24 Meters	$4,860.02
	44 Meters	$12,417.45
Two Span Truss	48 Meters	$9,998.70
Arch Truss	24 Meters	$6,507.20
	36 Meters	$11,577.04
Single Span with Anchorage	48 Meters	$17,303.20
Two Span with Anchorage	56 Meters	$13,361.93
TOTAL		**$76,025.54**

IV. Conclusion and Program Results

The initial difficulty in securing access to a high school is finding a champion for the effort. At this scholastic level, students themselves labor under a misconception that they have no engineering experience or expertise academically or otherwise. Once exposed to the software and some of the basic underlying engineering fundamentals, teachers and students alike were astounded at the sophisticated level of common sense involved with engineering design methodology. Further, many aspects of basic physics and the Newtonian laws were also clearly apparent and supported possible engineering applications in a variety of courses. Consequently, engineering as a field became less mystical and remote and more "reachable" to the students and teachers alike. Students initially lukewarm to engineering as a possible field were now enthusiastically considering this as a serious possibility for college studies.

The use of the *West Point Bridge Designer* as a tool for outreach was a remarkable success in several areas. As already described, the students have certainly taken a second look at engineering as a viable field of study. Teachers likewise enjoyed having the computer software medium to personally explore the tenets of engineering, but they also sincerely enjoyed the experience of watching the students as they turned on to this new avenue of learning. Finally, this outreach fostered a renewed working relationship between the local high school faculty and the University as cooperative partners in education. As an interesting footnote, it was apparent that these students were already clearly computer literate. This generation is well traveled on the information highway.

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