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

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This paper describes the use of a specially developed computer-aided design (CAD) software package as a vehicle for outreach to high school students. The CAD package was conceived and developed for future use in a nationwide engineering design contest, to be administered as part of the West Point bicentennial commemoration in the year 2002. In preparation for that event, the software has been used successfully in two different high school outreach activities. Student feedback from these activities has validated the concept of a CAD-based outreach project and provided useful suggestions for improvement as well.

Called the **WEST POINT BRIDGE DESIGNER**, the software guides the user through the design of a truss-type highway bridge, based on a specified design scenario. The program was developed with three principal objectives in mind:

- 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.
- To focus attention on West Point’s role as America’s first engineering school and on the contributions made by West Point graduates—past and present—to the design and construction of the nation’s infrastructure.

The design scenario used by the **WEST POINT BRIDGE DESIGNER** is both realistic and open-ended. The user is asked to design a modern replacement for the Dunlap’s Creek Bridge, the first iron bridge built in the United States\(^1\). The structure must be a simply supported truss. The only other constraints on the design are a specified span length, a maximum height restriction, and a 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. Members of the truss may be individually defined, using any of three different materials (carbon steel, high-strength steel, and aluminum), two different cross-section types (solid bars and hollow tubes), and 40 different member sizes. The design must be capable of carrying its own weight and the weight of a standard AASHTO truck loading\(^2\). The design objective is to minimize cost.

The software is written in the Microsoft Visual Basic programming language. It runs on IBM-compatible personal computers with 486 processor or better, running Windows 3.1 or better. The program features a simple graphical user interface, which students are able to learn easily, even if they have little previous experience with computers.

The program’s main window (called the *Drawing Board*) is shown in Figure 1. To design a bridge, the user simply draws it on the screen with the mouse. Editing of the structure is similarly accomplished by pointing, clicking, and dragging the mouse. Member properties—material, cross-section geometry, and member sizes—are selected from drop-down lists.
Figure 1. The Main Window of the West Point Bridge Designer, showing a structural design in progress.

While facilitating creation of a structural model, the West Point Bridge Designer simultaneously enforces all of the constraints specified in the design scenario. Simple supports are automatically added by the program at startup. The boundaries of the drawing grid coincide with the specified span and height constraints; the user is prevented from drawing a joint or member outside the grid. Thus the West Point Bridge Designer facilitates the creation of a successful design by ensuring that none of the design constraints can be violated. The program also calculates the cost of the structure as it is created, according to an algorithm that accounts for material, fabrication, and construction costs.

Once the user has created a complete truss, he or she clicks a button to initiate a simulated load test of the structure. The program (1) checks the structural model for consistency and stability, and warns the user if either of these conditions is not satisfied, (2) conducts a structural analysis of the current truss, considering its self-weight and the standard AASHTO truck loading at seven successive positions along the length of the bridge; (3) calculates the maximum force in every member in the truss; (4) calculates the strength of every member, with respect to tension yielding, compression yielding, and buckling; (5) compares calculated members forces and strengths; and (6) identifies any members whose strength is inadequate.  Finally, the program generates and displays a 3-dimensional animation of the load test, showing the AASHTO truck crossing the
bridge. As the truck moves, the bridge deflects in response, and members change color to indicate the severity of loading. If a member fails, the animation concludes with a reasonably realistic depiction of the collapse. The load test animation is illustrated in Figures 2 and 3. Note in Figure 2 that truss deflections are exaggerated significantly for clarity.

![Image of bridge with AASHTO truck loading in progress.](image)

**Figure 2. The Load Test Animation with AASHTO truck loading, in progress.**

The animation is much more than just entertainment. It is intended to help the user visualize the completed bridge and, more importantly, to gain a qualitative understanding of structural behavior—to see how loads, deflections, and member forces are interrelated. The use of color to indicate the intensity of force in each member is a particularly important visualization tool. It allows the designer to clearly see the tension and compression “load paths” that make a truss work, and to easily identify portions of the structure that are under- or over-designed.

A user of the **West Point Bridge Designer** needs no prior knowledge of engineering to produce a successful structural design; but a user who wants to learn about the subject is provided with ample opportunities to do so. The software package includes an extensive Help utility, that explains the mathematical and physical concepts on which the structural analysis and design are based. The Help file provides a recommended methodology for pursuing an optimal design. Users who take the time to do some exploration here will be rewarded with hints and techniques that will substantially improve the cost-effectiveness of their designs.

The **West Point Bridge Designer** received its first major trial in February 1996, when it was used as part of the observance of National Engineers Week. Every year, West Point’s Department of Civil and Mechanical Engineering supports this event by inviting students from a local high school to attend an afternoon of presentations, demonstrations, and hands-on activities designed to stimulate interest in engineering. This year 83 11th and 12th grade students participated. They were divided into three groups and rotated through three different workshops—one where they performed a simple tension test on a steel specimen, one where they mixed a small batch of concrete, and one where they designed a truss using the **West Point Bridge Designer**. This third workshop was set up in the Department’s Computer-Aided
Design Laboratory, equipped with 36 computer workstations. The time available for each group was limited to just 30 minutes. Within this available block of time, each group was given a very brief introduction, then coached through the design of a simple (but sub-optimal) bridge design. After this 15 minute tutorial, the students were allowed to work individually, with the objective of improving their designs (i.e., reduce their cost) as much as possible within the remaining time. A small award was offered for the best design.

This initial trial of the \textit{WEST POINT BRIDGE DESIGNER} was intended primarily to identify software bugs; thus no formal assessment of student perceptions or performance was done. Nonetheless, the authors were able to make a number of important and encouraging observations about the suitability of the software as a vehicle for high school outreach. Of the 83 students who participated in the workshop, \textit{every one} was able to successfully complete the tutorial, creating a simple bridge design that passed the simulated load test. And even though the time available for individual work was limited, most of the students were able to perform five or more new design iterations before the workshop ended. Most were able to achieve a modest improvement in cost-effectiveness; several did spectacularly well, achieving over 30\% cost reduction through geometric reconfiguration of the truss and improved member selection. Verbal feedback from the participants was very positive. The authors also discovered a number of problems with the user-interface, all of which were addressed in the next version of the software.

The \textit{WEST POINT BRIDGE DESIGNER} was used in a similar setting in July 1996, during West Point’s Invitational Academic Workshop. This week-long event is run every summer by the Director of Admissions and is intended to introduce high school juniors to the West Point academic environment. Several different academic departments participate in the program. This year, the portion of the program administered by the Department of Civil and Mechanical engineering included three workshops—a mechanical design project using Lego construction kits, a concrete mix, and a CAD project using the \textit{WEST POINT BRIDGE DESIGNER}. The location and format of the CAD project were identical to those of the earlier National Engineers Week workshop. The 111 student participants were organized into four groups so that, again, each student would be able to work at his or her own computer for the duration of the CAD project. Qualitative observations of student performance were virtually identical to those of the Engineers Week workshop described above.
On this occasion, however, students were also asked to complete a short written survey at the conclusion of the workshop. Specifically, the students were asked to (1) rate the workshop, on a scale of 1 to 10; (2) rate their interest in civil or mechanical engineering prior to the workshop, on a scale of 1 to 10; and (3) rate their interest in civil or mechanical engineering after the workshop, on a scale of 1 to 10. All 111 students participated in the survey. Their average rating of the entire program was 8.96. Their average interest was 6.50 prior to the workshop and 8.23 after, an average delta of +1.73. Only one student indicated a decline in interest. 20 participants indicated that their interest level stayed the same, and a majority of these (14) rated their level of interest either 9 or 10 (indicating that there was little or no possibility of improvement).

It must be emphasized that these assessment results pertain to the entire workshop, consisting of three different, high-quality, hands-on projects. Thus the very positive outcomes cannot be attributed entirely to the West Point Bridge Designer. Nonetheless, many students added narrative comments to their surveys, and all that mentioned the CAD experience were positive. A typical comment suggests that the load test animation feature was particularly effective in stimulating interest: “It gave me a smile on my face to see my design actually work when the truck went over it.”

Refinement of the West Point Bridge Designer continues, with the ultimate objective of using the software as the vehicle for a nationally administered engineering design contest for high school students. Current plans call for distribution of the software and administration of the contest entirely via the Worldwide Web. Much planning and development work remains before an event of such scope and complexity can be achieved; but the initial trials of the West Point Bridge Designer described above have convinced the authors that the concept of a CAD-based outreach project is indeed a viable approach for stimulating high-school students’ interest in engineering and design.

Educators who are interested in using the West Point Bridge Designer can download a free copy of the software from the USMA Department of Civil and Mechanical Engineering worldwide web site (http://www.dean.usma.edu/cme/civilsoft.htm).

REFERENCES

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