

## **An Interactive Steel Connection Teaching Tool - A Virtual Structure**

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### **ABSTRACT**

In this paper we describe the design and development of a web-deliverable interactive 3D virtual steel sculpture that can provide an effective learning opportunity and 24-7 access to engineering students and educators. Steel connections play important roles in the integrity of a structure, and many structural failures are attributed to connection failures. A good connection design requires the engineer to have a good understanding of the mechanics and steel behavior. In recent years, in order to help students better understand various connection types, many schools have acquired steel sculptures. A steel sculpture is a physical system that shows forty-eight types of connection found in standard construction practices. Unfortunately, because of its size and location (eight feet tall, weighs nearly 2500 pounds and usually erected outdoor), students do not always have easy access to it. The interactive virtual sculpture described in the paper provides an effective learning alternative. It allows the students to see the structure from multiple points of view anywhere anytime, and shows the close up view of each connection with description of how it may be used, potential failure modes, sample calculations, and field examples.

### **INTRODUCTION**

The Accreditation Board for Engineering and Technology (ABET) requires that all civil engineering graduates demonstrate that they can apply knowledge of four technical areas appropriate to civil engineering. Usually structural engineering is one of these areas. To meet the structural competency requirement, students take a design course in steel or reinforced concrete after they have completed the structural analysis course. A typical introductory level steel design course includes the following topics: determination of load combinations with appropriate load factors; sizing of tension (axial), compression (columns), and flexural (beams and girders) members; and

design of tension connections using mechanical fasteners as well as welds. In some cases, an instructor may be able to cover additional topics such as shear-moment connection design. Furthermore, for a typical 15-week long semester course, approximately one to two weeks are devoted to connection design.

The lack of emphasis (about 10 % of the course) on connection design is by no means a reflection of its significance to the integrity of a structure. Instead, it is due to the time constraint and the common belief that connections are standardized details that should be left to the fabricators and detailers. However, the connections are the glue that holds a structure together. Historically, connection failures have contributed to many structural failures, for example, the Hartford Civic Center in 1977 (Smith and Epstein 1980) the Hyatt Regency Hotel in Kansas City in 1980 (Pfrang and Marshall 1982) and more recently, the I-35W Bridge in Minneapolis (Holt and Hartmann 2008). Since the Hyatt Regency failure, many state licensing boards have made the connection design the responsibility of the engineer-of-record. Moreover, there are situations for which standard connection types would not be applicable and engineers are required to design connections unique to a structure. A good connection design requires the engineer to have a good understanding of mechanics and steel behavior and know the fabricator's limitations and experience. Often, what may appear to be an acceptable design (theoretically), in practice, it may not be feasible to fabricate in the shop or in the field. AISC Code of Standard Practice (AISC 2005) recommends the engineers to work closely with the fabricators and detailers while designing the connections. Hence, for these reasons, it is important that students, preparing for practice in structural engineering, develop a good understanding of connection design limitations and assembly. Moreover, because of their three-dimensional nature, students have more difficulty understanding the assembly of connections than the design of major components such as beams and columns.

The web-based interactive 3D tool (virtual sculpture) described in the paper aims to overcome some of the obstacles described above. Currently, to our knowledge, there are no web-based interactive 3D tools that show in detail how various components of a steel structure are connected. Moreover, no researcher (or educator) has generated finite element models showing stresses within each possible connection type. Our interactive virtual steel sculpture will help students better visualize how members could be connected. Unlike the physical steel sculpture, this interactive virtual tool is accessible to students and educators 24-7 in the United States and abroad. The virtual structure also benefits other affiliated personnel such as architects, design technicians (drafting people), and construction managers. Moreover, this tool can allow other educators and engineers to contribute to the database of design calculations and field examples.

## BACKGROUND

**Physical Steel Structures.** Steel connections have primarily been designed as 2-dimensional elements (x-y and z-y planes) despite the fact that their load bearing behavior is 3-dimensional. Combining two 2-D designs to yield a connection that supports a 3-D load bearing behavior is a concept that is usually very difficult for

students to visualize. For example, when two beams (Girder B3 and Beam 3A) are oriented normal to each other as illustrated in Figure 1, we often use two angle sections to connect them. One of the angles will be in the front face of beam 3A and the other angle will be placed at the back face of beam 3A. The bolts will then connect all three elements together as shown in Figure 1 – View B.

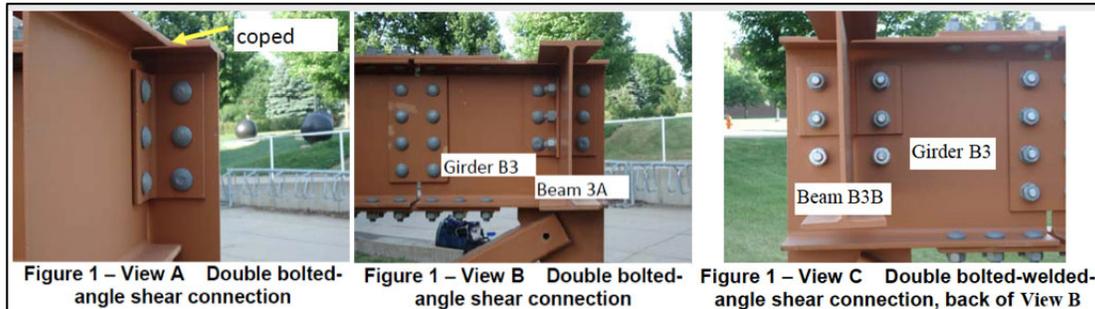


Figure 1 shows various views of the shear connections between a girder and two beams (Beams B3A and B3B connect to Girder B3). If we only were shown view A, we would then conclude that the connection is a single-angle bolt connection. If we were given view B, then it is obvious to a structural engineer that it is a double-angle bolt connection. Further examination of the connection reveals that it is actually a two-double angle bolt and bolt-weld connection. View C shows the back-side of view B. It would not be easy to show all the details for this connection on a blackboard (or whiteboard), and would be difficult for most students to visualize. In practice, the details would be shown as a series of two-dimensional drawings such as the typical shop drawings that would be provided by the fabricator to the engineers for review and approval. Although the shop drawings depict exactly how the connections are to be assembled, they are not easily understood by the students.

Taking students to actual construction sites is one way to help them see how steel members are assembled. Although this is a good approach, it is a major challenge to find construction projects that are nearby and during the term in which the design course is taught. Often, liability issues also prevent the faculty from taking students to construction sites. Because of these issues, many faculty members have resorted to taking photographs of connection types from construction sites and then showing them to their students. Unfortunately, the photographs still do not show the true 3-dimensional nature of connections.

In the summer of 1985, after seeing the inability of his students to visualize even simple connections, Professor Duane Ellifritt of Florida State University designed a steel connection sculpture as a visual aid to teach his students about the many ways steel members could be connected (Florida State University 1998). This thirteen feet tall sculpture has now been duplicated (duplications are only eight feet tall) and erected at over 135 campuses across the United States. In addition to the physical sculpture, the American Institute of Steel Construction (AISC) also has prepared a teaching guide for the connection types (Green et al. 2008) which can be downloaded from the AISC website.

**Interactive virtual learning tools.** In this paper the term interactive virtual learning tool is used broadly and because of this broad usage, it can refer to a website with static web pages. At the other end of the continuum, an interactive virtual learning tool can be a highly integrated system, including the associated infrastructure, that:

- a) substantively incorporates 3D virtual reality technology (i.e., an environment that represents objects with a high degree of fidelity),
- b) is immersive, meaning that educational interactions occur within the environment making the environment a “place”,
- c) is a designed information space in which the information is explicitly represented and the educational interactions occur so that students are not only active, but actors, i.e., they co-construct the information space,
- d) overlaps and is an extension of the physical environment, thereby possessing the potential to enrich classroom activities, and
- e) can integrate heterogeneous technologies and multiple pedagogical approaches (Dillenbourg, 2000).

Research on the educational benefits of interactive virtual tools is fairly recent and stems from the fields of computer graphics, cognitive psychology, visual cognition, and educational psychology. In general, these early research findings show that virtual learning tools can be more effective than traditional teaching tools (Dalgarno 2004; Shin 2003; Winn 2002). Research also shows that Virtual Reality (VR) technology is particularly suitable to mathematics and science education. VR technology can present abstract concepts in concrete terms, offers the opportunity to manipulate concrete objects, and to bridge manipulatives with other representational forms. Technologies, such as VR, can be used to create interactive learning environments where learners can visualize concepts easily and receive feedback to build new knowledge and understanding (Hmelo 1998; Bransford 1999). Computer simulations have been shown to be an effective approach to improve student learning and have the potential to help students develop more accurate conceptions (Kangassalo 1994; Zietsman 1986; Gorsky 1992). Research shows that the use of simulation tools often reinforces learning and leads to performance improvements in a variety of disciplines. Therefore, recently, there has been significant progress in development of computer based interactive learning tools in many different areas.

These early findings suggest the development of virtual learning tools has promise. In response, we are seeing the advancement of virtual learning tool projects in engineering and science. For example, Del Alamo (Mannix 2000), a professor of electrical engineering at MIT, created a web based virtual microelectronics lab for his students in 1998. At Johns Hopkins University, Karweit (2005) has simulated various engineering and science laboratories and instruments on the web. At the University of Illinois Urbana-Champaign (UIUC), researchers have developed a virtual laboratory for earthquake engineering (SSTE 2008). Kuo et al. (2007) have recently developed a virtual survey instrument (SimuSurvey) and studied the feasibility of introducing SimuSurvey in regular surveyor training courses to teach students how to operate virtual surveying instruments. Results of the study indicated improved student ability to use the instruments and positive attitude toward including SimuSurvey in regular surveyor training courses.

Although some authors have documented that interactive virtual learning tools can provide advantages over more traditional instructional methods (Ainge 1996 and Song 2000), studies of virtual reality projects are early and still relatively few and a need exists for further investigation of virtual learning tools in the undergraduate classroom (Strangman 2003). Therefore, we believe that this project, focused on developing and testing an interactive virtual steel structure as a part of learning connection design, has the potential to advance our understanding of how to design effective VR educational applications.

## **THE INTERACTIVE VIRTUAL STEEL STRUCTURE**

The virtual steel sculpture allows the students to view the connections from every possible angle by spinning the virtual sculpture 360 degrees in any direction. The individual connections can be examined individually as well by clicking on the connection of interest. This individual connection can be examined as well from every possible angle. Allowing the students to closely study the connection. The steel connections are numbered as well. By clicking on the number of the steel connection the student is presented with a new screen where additional information related to the various connections. Information such as sample calculations, images from the field illustrating examples from real world settings, and a description of the type of connection as well as the limitations of such connection. (A link to the actual sculpture will be inserted in the final draft of this paper – currently omitted for blind review purpose)

The interactive virtual steel structure is an accurate 3D model of the physical steel structure located next to the civil engineering building on the Purdue University campus. The sculpture was modeled to scale and can be viewed from any point of view.

### Technical Details

The interactive steel structure is deliverable via web or CD-ROM on standard personal computers (PCs and Macs). The platform for the project is based on the highest end in 3D interactive animation. We used Autodesk Maya software to model and texture the structure and to animate its functionality. Interactivity with the 3D components was programmed in C# using Unity 3D game development platform (Unity 2013). The choice of Unity platform was based on the following considerations:

- Unity has an optimized graphics pipeline that supports interactive rendering of complex animated 3D meshes and advanced lighting and textures even on computers with limited graphics capabilities.
- Unity interfaces seamlessly with major 3D animation tools (i.e. Autodesk Maya and 3D Studio Max) and file formats, and allows for instantaneous import and update of asset files and animations.
- It supports a wide range of publishing platforms, including: standalone builds for Mac OS and Windows; web delivery through the Unity Web Player Plug-in (3 MB); Wii and Iphone publishing.

The interactive steel structure is designed to run on hardware and software infrastructure that is already widely deployed in universities. Students will be able to use the virtual structure on low-end personal computers (PC/MAC) with a low-end graphics card.

## **DISCUSSION AND FUTURE WORK**

In this paper we have described the design and development of an interactive virtual steel structure for teaching students connection design and the mechanics and steel behavior. The virtual steel structure provides a solution to many of the problems associated with teaching connection design, as it provides students with 24/7 access to the structure, allows the students to see the 48 connections from multiple points of view, and shows the close up view of each connection with description of how it may be used, potential failure modes, sample calculations, and field examples.

Ongoing and future work includes formative and summative evaluations with students and faculty at Northwestern and Purdue University. Formative studies will assess usability and perceived usefulness of the interactive structure, and will collect feedback for design improvement. Summative studies will evaluate the educational efficacy of the interactive virtual structure. The student learning outcomes will be assessed using Bloom's six levels of intellectual behavior important to learning: knowledge, understanding, application, analysis, synthesis, and evaluation (Bloom 1956).

Although the primary goal of the virtual steel sculpture is to be incorporated in a steel design course, this teaching tool can also help students taking other courses such as senior capstone design, statics, mechanics of materials, and structural analysis. Furthermore, it has the potential to benefit new engineers, architects, engineering technicians, and construction managers. With the addition of sample calculations and field examples by colleagues from other countries, the virtual steel structure can also benefit students and faculty globally.

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