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Interactive Online Figures for the Core Concepts in Structural Steel Design

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Interactive Online Figures for the Core Concepts in Structural Steel Design Introduction

Abstract

This paper presents online interactive resources, or applets, covering the core concepts in an undergraduate structural steel design course. They were developed for AISC's Educator Resources website using GeoGebra, an online and open-source platform. The applets are intended to promote learning in steel design by cultivating a rich visual connection between AISC specification equations and the related engineering concepts. Many parameters involved in the simulated scenarios can be controlled by the user, allowing them to manipulate the items and visually gain familiarity with the relationship each parameter has with the mechanism being demonstrated. This is intended to combat the "plug-and-chug" mentality to which students often succumb in design courses. These interactive depictions of structural members, relevant plots, and animations provide students a unique online study aid. Further, instructors can use these tools during lectures or as customizable homework assignments. Currently, the available applets cover basic concepts in steel framing, flow of forces, steel material behavior, and limit states and design of tension members and simple connections. Applets are currently under construction that cover compression members, bending members, and members subjected to combined loading. This paper provides a brief description of each applet and suggestions about how best to utilize them in a steel design course. Finally, some preliminary student opinion data is presented showing their effectiveness in teaching.

Introduction

Interactive diagrams, graphs, and figures (herein referred to as interactive applets or tools) have been developed in the open-source web-based and mobile device-compatible platform GeoGebra [1]. Objects in GeoGebra can be programmed to follow mathematical relationships of physics and dynamics or any other the developer desires. Each parameter involved in the simulated scenario can be controlled by the user, allowing them to manipulate the item and visually gain familiarity with the relationship each parameter has with the mechanism being demonstrated.

The teaching and study tools that have been developed by the authors are interactive applets that follow AISC specification equations and other structural engineering concepts needed to express key concepts in structural steel design. Students have the ability to explore the relationships between various parameters such as member dimensions, applied loads, steel shapes material types, or other pertinent factors. While changing the parameters of a figure, the graphics of the activity are updated in real-time, giving instant feedback as to what changes are occurring in the given scenario. Not only are the graphics and plots updated but equations and resulting equation outcomes can also be displayed. The display of anything can be toggled. So, the governing equations, results, or plots can be hidden allowing students to make predictions of the outcome based on their input parameter values.

The interactive nature makes the applets powerful study tools. The seamless compatibility of GeoGebra with mobile devices is also a significant advantage of the platform over others since students are increasingly using solely their mobile phones or tablets for homework and studying. This makes the interactive applets powerful study tools that steer students away from blindly plugging values into equations based only on the information given in a written problem (i.e., "plugging and chugging").

This paper serves to introduce the applets and initiate the study of their effectiveness in conveying the core concepts of structural steel design and to discover how useful students feel these tools are in helping them study.

Topics Covered

As previously stated, the core concepts that are typically covered in an undergraduate structural steel design course. These are summarized in **Table 1** and are organized according to phases of the ongoing project to develop the applets. Essentially, phase 1 has been completed and are available for use by instructors. Phase 2 will be completed during 2021 and available near the end of the calendar year.

As structural steel design often comes in the beginning of students' experience in structural design. Typically, there is a bit of a learning curve surrounding how design problems are approached. So, some initial applets are aimed at orienting the students' view around building plans and flow of forces. Then, the typical flow of topics is tension members, connections, compression members, beams, and combined axial and bending. In addition, the later applets will cover some practical aspects of steel design that involve cost and constructability.

The full list subtopics and learning objectives are provided in **Tables 2** and **3**.

Applet Development

The functionality of GeoGebra used in these tools could essentially be described as a sophisticated graphic calculator with powerful geometric object tools built in. One is able to add inputs and corresponding outputs, both numerically and visually/geometrically, to portray a concept in an environment in which objects are defined by mathematical and geometric relationships and can be assigned mathematical and geometric relationships one to another. Therefore, planning the functionality of each applet required a certain level of familiarity with the platform.

Then, each core concept and subtopics were identified, and a series of applet storyboards were created. The goal for each applet was to provide an interactive figure that allowed students to instantly identify how the parameters of the AISC specification equations and/or calculations aligned with the physical properties of the steel component or structure (e.g., the figure). Further, where applicable, the authors sought to visually convey the flow of forces. With these goals in mind, the applets were developed through iterations, storyboards and draft applet versions until a satisfactory representation of the original idea was achieved.

A prescriptive description (tutorial) of how to develop applets in GeoGebra is not appropriate for this paper. But, interested readers are invited to reach out to the authors for more information. Being an open-source platform, there are many resources available online with a basic search.

Table 1 Project Phases and Summary of Topics Typically Covered in an Undergraduate Structural Steel Design Course

Phase	Core Topics	Typical Timing within an Undergraduate Steel Design Course
Phase 1 Completed	- Gravity & Lateral Framing - Steel Material Behavior - Tension Members - Simple Connections	**Early** (~40% of the course) - 15-week semester: weeks 1-6 - 10-week quarter: weeks 1-4
Phase 2 Coming in late 2021	- Compression Members - Flexural Members - Combined Loading & Stability Basics	**Mid to Late** (~60% of course) - 15-week semester: weeks 6-15 - 10-week quarter: weeks 5-10
	- Practical Aspects of Steel Design	**Not uniformly adopted** (N/A) - Distributed throughout the term

Table 2 Phase 1 Activities, Topics Covered, and Learning Objectives (Completed in 2020)

Core Topics	Topics	**Learning Objectives** "After interacting with the GeoGebra activity, students will (be able to):"
Gravity & Lateral Framing: 4 activities Students will learn about gravity framing and flow of forces by interacting with 2D and 3D figures demonstrating tributary area, metal decking direction, and the resulting loading on simple supported steel beams and supporting columns. The flow of forces will also be demonstrated for lateral force resisting systems.	- Flow of forces - Using tributary area vs. following loads through framing - Loading of members - Live load reduction - Various bracing schemes (CBF, EBF, chevron, etc.)	- visualize beam and column tributary areas - identify which beams are loaded by metal decking - compare beam and column gravity forces using tributary areas and flow of forces via framing - visualize how lateral forces are transferred through a LRFS
Steel Coupon Demos: 2 activities These activities will give students the power to control semi-simulated steel coupon tests where steel type can be changed, and multiple tests can be carried out to reproduce evidence for expected strength values using randomized "results". Plots will be generated progressively so as to build the story for each "test" conducted.	- Steel behavior and stress/strain curve definitions (F_y, F_u, etc.) - Nominal vs. Expected properties - Ductility - Relative performance of various structural steels - Eng. vs. True Stress & Strain	- identify the various regions and points along the steel stress/strain curve. - recognize the difference between nominal and expected steel material properties. - recognize the relationship between ductility and yield strength
Tension Members: 4 activities These activities will show semi-simulated member tests with interactive parameters of member gross and net cross-sections. Students will observe the results and related AISC specification equations.	- Yield and rupture limit states - Net section, incl'd staggered bolts - Whitmore Section - Effective Area - Shear Lag	- identify the physical differences between yield and rupture limit states - connect the terms of the AISC specification equations and member geometry - visualize how forces flow through members and how this determines effective net area and shear lag
Simple Connections: 4-6 activities Bolted and welded connections will be explored with applets showing the effect of bolt and weld sizes, number of bolts and welds, shear/loading conditions, geometry and configuration, and location and orientation of loading. Fundamental concepts will be connected with the various limit states and connection strengths of simple connections. Those include net section, shear lag, block shear, and combined shear and tension.	**Bolts and Welds** - Limit states of shear, bearing and tear out, tension, combined shear and tension, fillet welds - Shear area/condition, material type, and bolt strength - Equal bolt force transfer (plastic redistribution) - Components of $1.392(D)L$ - Base metal and weld strengths **Simple Connections** - Tension, shear, block shear	- connect the AISC specification equations to the physical strength of bolts and welds - visualize the flow of forces through simple connections and relate this to the limit states involved - distinguish between the strength of the connecting elements and connectors (bolts or welds) and understand their relationship to overall connection strength - navigate the design of various simple connections

Table 3 Phase 2 Activities, Topics Covered, and Learning Objectives (Coming in 2021)

Core Topics	Topics	Learning Objectives "After interacting with the GeoGebra activity, students will (be able to):"
Compression Members (3-5 activities) Limit states, design, and crucial conceptual aspects of flexural & local buckling explored by demonstrating the effects of boundary conditions, cross-section, and bracing in various scenarios. Close attention will be paid to elastic vs. inelastic buckling and some theoretical aspects will be interspersed to deepen students' understanding.	- Elastic/inelastic flexural buckling; "the buckling curve," and the relationship to Euler buckling - Effect & concept of residual stress - Effect of boundary conditions - Effect of bracing - Local buckling & plate buckling - Effect of material strength, especially for slenderness ratio	- identify the physical differences between flexural & local buckling - connect physical meaning to AISC specification equations/terms - appreciate the physical meaning of slenderness ratios - be prepared for implications of future high strength steels (local buckling) - navigate compression design
Flexural Members (3-5 activities) Limit states and design of flexural members (mainly in context of beams) will be covered through applets that strongly tie students' prior understanding of bending theory to the AISC specification while expanding their knowledge to plastic design.	- Yielding, LTB, FLB, and WLB - Effect of bracing for simple support, continuous, and cantilever beams - Reinforcement and expansion of beam theory skills/knowledge - Serviceability condition (deflection) vs. limit state and role in design	- identify the physical differences between yielding, LTB, LB limit states - recognize the difference between section and plastic moduli - conceptually connect flexural & local buckling to LTB and flex. LB - navigate beam/flexural member design
Combined Loading (3-4 activities) These activities will demonstrate core concepts of combined loading and structural stability, as covered in the AISC Spec., by giving students direct control over the key parameters for components and frames.	- 2^{nd} order analysis: concept and role in design for combined loads - AISC Ch. H - P/M interaction diagram - Basics of the B_1B_2 approx. 2^{nd} order analysis method - Basics of the Direct Analysis Method	- differentiate 1^{st} and 2^{nd} order analyses and recognize why combined loading req's 2^{nd} order - synthesize combined loading and structural stability concepts - visualize this difficult yet crucial aspect of steel design - navigate design process
Practical Aspects of Steel Design: (4-6 activities) Added dimensions of cost, efficiency, and/or constructability will be implemented to additional versions of applets and topics from Phase 1 (framing, tension members, and simple connections) as well as those proposed in here Phase 2 (above).	- Relative costs of various options in • framing design • tension member design • beam & column design • bolted vs. welded connections - Fit up, tolerance, constructability of simple connections - Visualizing beam and column fit-up, column splices, and bracing	- gain familiarity with the budget and scheduling consequences of design choices - visualize how members fit together and/or conflict - understand why sometimes non-optimal sizes are selected for constructability

Examples of Applets

Although Phase 2 is still ongoing, a set of examples is ready for use and will be published on the AISC Teaching Aids website [2] in early 2021. A few examples are provided here to exhibit GeoGebra's capacity to convey structural steel design concepts.

This applet (#1 below), on the basics of gravity framing, provides students many combinations of loadings and geometries with which to practice their calculations. This is one of the first developed during Phase 1 and consequently one of the least "animated". Another pertinent example is this applet (#6 below) covering the basics of structural steel tensile material behavior. This activity covers the stress/strain regions and paves the way for ultimate limit state and plastic design philosophies by providing a relatable presentation and a simple explanation of the idealized elastic-perfectly-plastic behavior utilized in steel design. Finally, this applet (#7 below) demonstrates the difference between nominal and expected steel strength.

Design calculations for tensile members (bolted here, #9, and welded here, #10), give students ample opportunity to practice variations of basic members. Finally, **Table 4** provides the full list of available applets.

Table 4 Complete list of Currently Available Applets

Core Topics	Topics
Gravity and Lateral Steel Framing	1) Gravity System Basics 1 – Metal Decking on Steel Beams https://www.geogebra.org/m/zchpnhjk#material/xfsh3zz4 2) Live Load Reduction https://www.geogebra.org/m/zchpnhjk#material/qnp4sh4g 3) Gravity Framing Basics 2, Irregular Floor Plan https://www.geogebra.org/m/zchpnhjk#material/wutp5fdg 4) Gravity Framing Basics 3, Multistory Building https://www.geogebra.org/m/zchpnhjk#material/vf8xcy5f 5) Lateral Framing Basics https://www.geogebra.org/m/zchpnhjk#material/wvunnsus
Steel Material Behavior	6) Tensile Behavior https://www.geogebra.org/m/zchpnhjk#material/a873rqbe 7) Expected vs. Nominal Material Strengths https://www.geogebra.org/m/zchpnhjk#material/fwmcqhxy
Tension Members and Simple Connections	8) Tension Members and Simple Connections - Overview https://www.geogebra.org/m/zchpnhjk#material/kjgjex8k 9) Bolted Tension Members https://www.geogebra.org/m/zchpnhjk#material/ywh2qdgt 10) Welded Tension Members https://www.geogebra.org/m/zchpnhjk#material/zabdgfgy 11) Block Shear https://www.geogebra.org/m/zchpnhjk#material/jxatqfmy

Initial Effectiveness Survey Data

At the time of the authors' most recent course offering of steel design, in the 2020 fall term, only a few of the applets were ready for deployment. Therefore, limited initial student opinion data was able to be collected. The students were provided the links to the tools, but no additional prompts were given so as not to influence the student opinion of the applets themselves.

Two gravity framing applets were shared with the students, Gravity System Basics 1 and 3. Afterward interacting with the tools, students were asked to respond to the statement "This interactive tool helped me understand how gravity forces flow through gravity framing." Overall, the students widely agreed that the tools were helpful, with about 70% responding "Agree" or "Strongly Agree" for each applet, as is shown in **Fig. 1**. Additionally, Informal discussions and feedback from students about the tools led to improvements to be made.

Survey data will be gathered on the full set of applets in the 2021 fall term since all applets will be developed and will be incorporated into the course curriculum. It is expected that when students are exposed to this type of tool on a consistent basis, that positive response rates will increase dramatically.

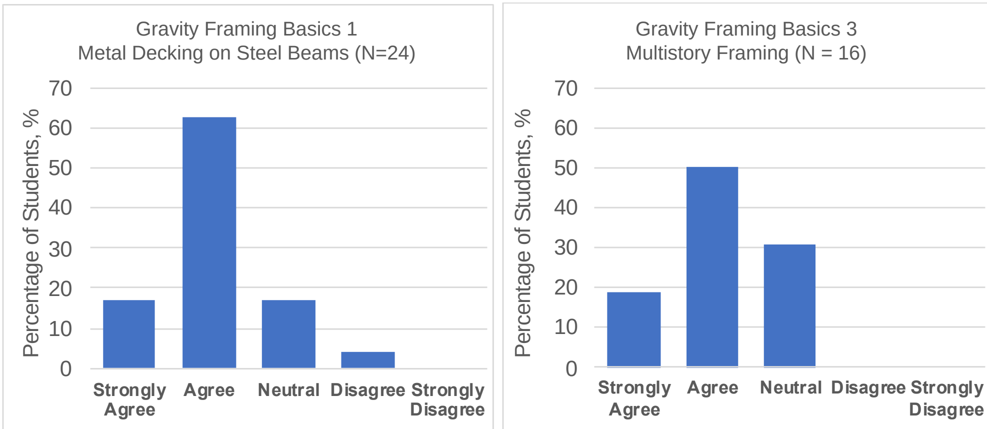

Figure 1 Student survey responses to the prompt
"*This interactive tool helped me understand how gravity forces flow through gravity framing.*"

Student and Instructor Use

These interactive media could allow students to gain a sense of the physical meaning and relative impacts of design parameters. The dynamic nature of the activities can aid in visualization, which will foster understanding of the core concepts and thereby avoid the famous "plug-and-chug syndrome" that plagues design courses. Even just "playing" with the applets, one can tend to "get a feeling" for how the equations and behaviors "work". In a more intentional setting, like students studying their notes after class, etc., students may benefit greatly from seeing the equations that the instructor covered in lecture come to life in front of them.

Instructors can use the applets as demonstrations during lecture and provide the links to the class as extra study references. Or instructors could develop novel homework problems or assignments that center around the use of these tools. As a starting point, each activity has a brief description and prompt about what to look for while the user is "playing" or suggested ways of how to use the applet. This could help instructors to utilize the applets in a way that best suits their style and help guide students' learning while using the tools.

AISC Teaching Aids are free for anyone to use. Further, the opensource platform makes it very easy to incorporate new applets. Collaborations are welcome and interested parties are encouraged to reach out to the authors and/or AISC University Programs staff.

Summary and Conclusion

Interactive diagrams, graphs, and figures (i.e., interactive applets) have been developed in the open-source web-based platform GeoGebra [1]. The teaching and study tools that have been developed to follow AISC specification equations and related structural engineering concepts to efficiently convey key concepts by giving students the ability to explore the relationships between various parameters in a real time and visually interactive environment.

Preliminary data from a student survey on two of the applets shows that students broadly agreed the tools helped them understand the core concepts addressed. Future study will include survey data on all applets and will also explore the different ways in which students and other instructors utilize these interactive figures to learn and teach structural steel design.

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References

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