

## Web-Based Java Applets for Teaching Engineering Mechanics

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### Abstract

A series of novel Web-based instructional units for teaching structural mechanics to undergraduate students are developed. The instructional units are centered on computer programs written in the platform independent object-oriented Java programming language. The Java applications are embedded in World Wide Web pages (where they are called applets) and are thus available via the Internet to students and instructors throughout the nation. The instructional units are self-contained and independent and can be easily integrated in a variety of courses. Examples of applets developed include: shear, moment and deflection of beams, computation of section properties of sections built up from standard geometric shapes, analysis of statically determinate trusses, and shear center for open and closed section thin-walled tubes. The applets make extensive use of graphics and allow for significant interaction. The advantages of using Java and the World Wide Web for teaching are discussed and examples of the use of these applets in the classroom are presented. An important aspect of the work is to simulate development of similar materials. The instructional units provide necessary resources for instructors in the form of source code and suggestions for adaptation and incorporation into courses. Evaluation of the educational effectiveness of the units is also discussed.

### Introduction

Many educators have realized the value of computer-based tools for enhancing engineering education. The capability of the computer to interact with its user, to compute and then display the consequences of that interaction in a dynamic form provides an avenue for learning that is simply not available in the classroom or textbook. Educators have exploited this capability by developing educational software to solve standard engineering problems and illustrate fundamental engineering concepts and phenomena. Such programs range for simple routines written in a programming language to full multimedia packages.

The advance of technology in the form of the relatively new Java programming language and the World Wide Web offers real opportunities for enhancing the quality of engineering education. The World Wide Web is a popular vehicle for publicizing information in text or graphical form over the Internet. In recent years it has also become a valuable resource and tool for educators. Its strength and popularity arise from the fact that it provides access to information that is time and location independent. Web pages have a significant weakness, however, in that they only offer

static access to information in the form of text and pictures. They lack the very capabilities of interactivity and dynamic display that can make computers such powerful educational tools.

The Java programming language now provides this capability. Java is an object-oriented programming language that has capabilities similar to advanced programming languages such as C++. What makes Java unique is that it is platform independent. Java applications can be embedded in web pages, where they are called applets and can be executed from within the web browser. Java and the World Wide Web thus have the potential to be very powerful tools for engineering education. A set of instructional units published on the web using Java applets can interactively and dynamically illustrate key engineering concepts. These units are usable by any student or instructor (throughout the nation and the world) with a computer and an Internet connection.

It should be noted that there are other competing technologies besides Java for developing active Web content. The most important of which are the Microsoft COM/ActiveX technologies, Active Server Pages (ASP) and Dynamic HTML (DHTML). It is difficult and time consuming to develop engineering applications requiring significant computations using ASP and DHTML. Although ActiveX applications can be developed using Visual Basic or Visual C++ and can easily be deployed over the Internet, there are several disadvantages to using ActiveX. ActiveX is not machine independent and is usually only available for the Windows platform. There are also security problems associated with ActiveX. ActiveX applications can directly access client hardware and file systems and require a global and bureaucratic registration system to ensure security.

### **Format of the Instructional Units**

Each instructional unit consists of a series of HTML (HyperText Markup Language) documents containing Java applets. The HTML pages have a standard format to facilitate learning. The instructional units developed are small, self-contained, and independent and address only a single concept. This allows instructors to select units, that are best suited for their particular context and does not impose a course structure. The HTML documents in which the Java applets are embedded have a standard format in that they all contain the following information:

1. A statement of the educational goals of the instructional unit and a description of the subject matter and fundamental engineering concepts being addressed. This description provides the necessary background material such as relevant principles, underlying equations and notation.
2. A description of the applet. This includes the input required, expected results, and description and interpretation of results.
3. A series of example problems and exercises to assist students in exploring the engineering concepts being presented.
4. Suggestions for possible projects and future work in applying the knowledge gained from using the applet to practical engineering problems.
5. Supplemental information (such as source code, development guidelines, suggestions for incorporation and adaptation) to assist other instructors in using the applets and in developing their own.
6. An on-line evaluation form designed to assess the attitudes of users and the educational effectiveness of the instructional unit.

## Description of Applets

In this section a brief description of a few applets that were developed is presented. The reader is encouraged to visit the web site <http://www.engapplets.vt.edu> for detailed descriptions and instructions.

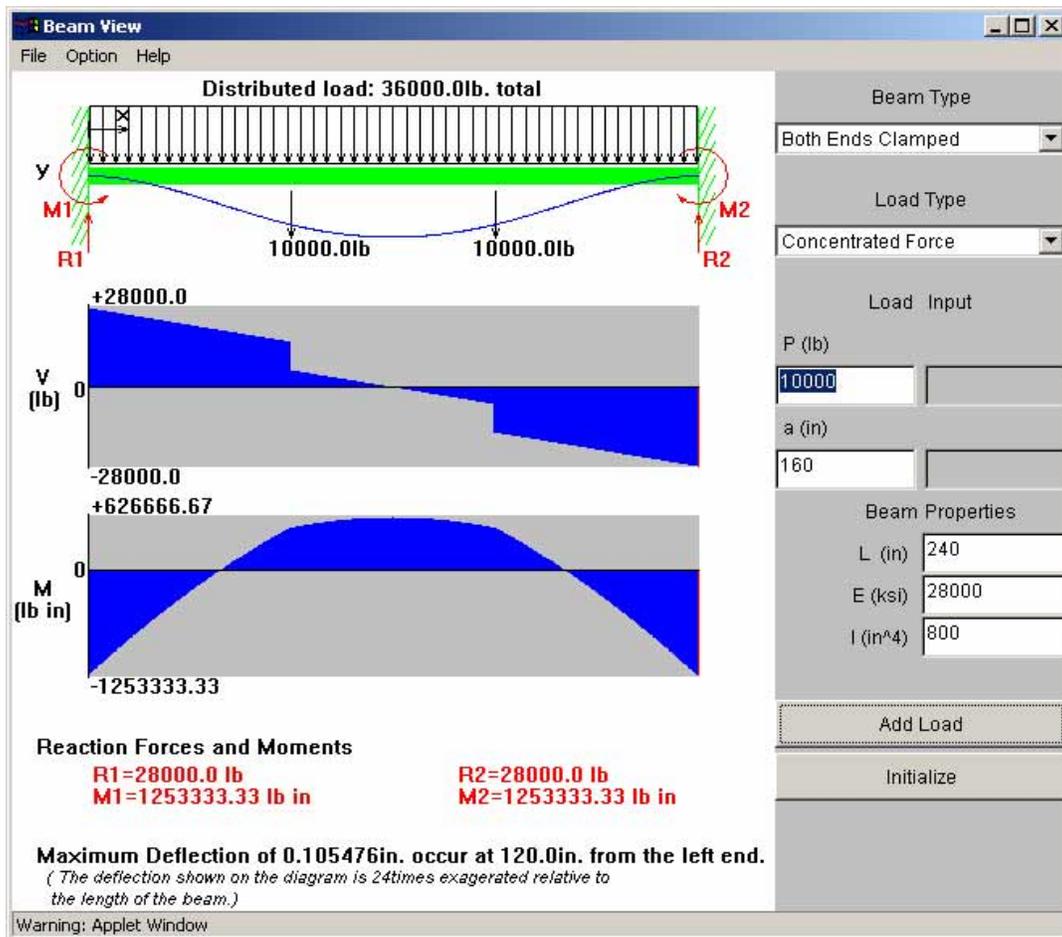
### Shear Moment and Deflection of Beams

A common problem in most engineering mechanics courses is the construction of shear, moment and deflection diagrams for beams subjected to transverse loads. For simple loading conditions and beam configurations this is a relatively straightforward task. However, for more complex loading conditions and beam configurations, such as a fixed-fixed beam subjected to linearly varying loads, this can be very time consuming. These diagrams are required for the design for flexural members. Deflection calculations are required to ensure against the possibility of excessive deflections.

An applet for computing the shear, moment and deflection at a number of points along a beam has been developed. This applet also draws the shear, moment and deflection diagrams. The types of beams that can be considered include: a) cantilever beams, b) simply supported beams, c) propped cantilever beams, and d) beams with both ends fixed. A variety of loads can be applied to the beams including uniformly distributed load, concentrated loads, linearly varying loads, and moments at the ends or at intermediate points along the beam. These loads can be applied in any combination. The applet uses the principle of superposition to obtain the combined effect of the loads

The applet calculates the shear, moment and deflections at specified intervals along the beam. It also computes the support reactions and draws the shear, moment and deflection diagrams. Exact equations for the shear force, bending moment and deflection along the length of a beam with given support conditions and subjected to the loads described above are given in several textbooks and design manuals. The program uses the equations presented in Roark and Young [5].

Figure 1 shows the applet and the results for a fixed-fixed beam subjected to a uniformly distributed load and two concentrated loads. Although the applet itself can be run within any Java-enabled web browser such as Internet Explorer, Netscape Navigator or HotJava the application is displayed in a separate window. This allows the user to run the application and at the same time view instructions in the browser. The applet employs a graphical user interface with several well-defined areas so the student can clearly see all of the input parameters and the computational results immediately. The beam is displayed at the top along with the support conditions and applied loads. The picture of the beam also shows the positive directions of the reactions. The shear, moment and deflection diagrams are displayed directly below the beam. These diagrams are updated as new loads are applied so that the effect of these loads on the shear, moment and deflection can be seen immediately. The right hand section of the screen is reserved for input. Here the student can select the type of supports, the type of load to be applied and enter loading parameters. The applet also allows the student to enter data in a tabular format and display the results in a table. This is a useful feature since the results of the analysis can be copied (via the clipboard) and used as input to another application such as a spreadsheet or a beam design program.



**Figure 1:** Beam Span Analysis Applet

The BeamSpan Analysis applet allows students to study how the distribution of shear, moment and deflection changes under each load. It also demonstrates graphically the effect of different support conditions and of adding different types of loads and thus serves as a very useful tool for studying these concepts without having to perform the many lengthy and tedious computations by hand.

### Sections Properties of Composite Sections

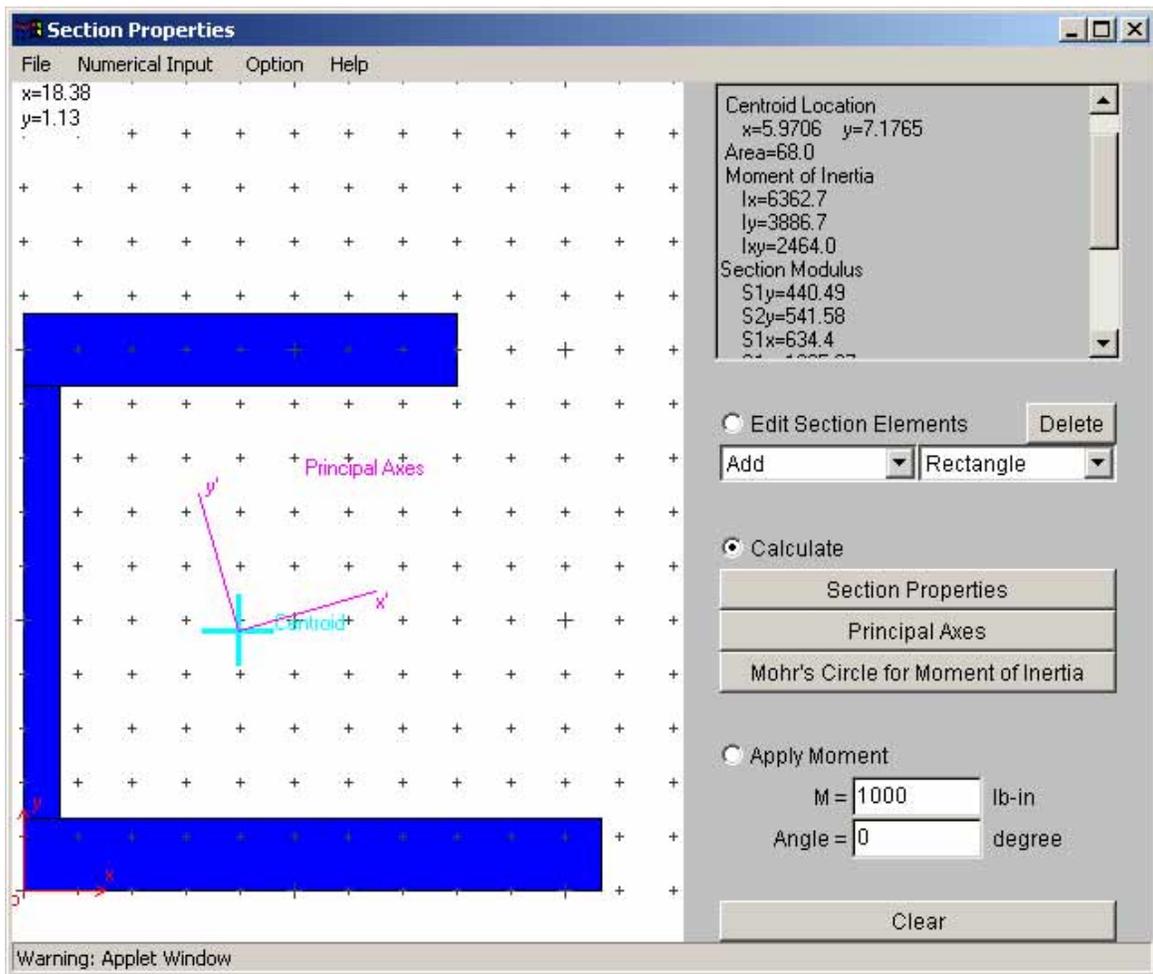
An important topic in undergraduate mechanics courses is the computation of properties of planar areas. Examples of such properties include the area, location of the centroid, second moment of area or area moments (also know as moments of inertia) and products of inertia. These properties have many applications. In fluid mechanics they are needed to determine hydrostatic pressure distribution. In mechanics they are used to describe the distribution of stresses in beams, shafts, and columns resulting from transverse and torsional loads and for computing deflections of beams. These section properties appear frequently in design formulas used in fluid mechanics, structural mechanics and structural design. Thus, it is important for students to become familiar with the methods used for computing these quantities.

An area can be divided into two or more simple areas such as rectangles, triangles, polygons, circles and ellipses. Such areas are called composite areas. Standard structural shapes such as I beams, channels, angles are frequently assembled to form more complicated members. The properties of standard structural shapes are available in design handbooks such as the AISC LRFD Manual of Steel Construction [1]. For composite sections, the total area is the sum of the separate areas and the resultant moment of inertia about any axis or plane is the sum of the moments of inertia of the component areas. The parallel axis theorem is used to transfer the moment of inertia of each composite area to the desired axis. When an area, such as a hole is removed from a larger area its moment of inertia is subtracted from the moment of inertia of the larger area. For many applications it is important to determine the maximum and minimum second moments of inertia, and the orientation of the axes about which the moments of inertia of the area are a maximum. The particular rectangular axis for which the second moment is maximum and minimum is called the principal axis of the area. The product of inertia is zero with respect to the principal axis. Procedures for computing section properties are outlined in several mechanics textbooks [2, 3, 4].

The Section Properties applet is a program for computing section properties of composite sections. With the applet, students can build a section consisting of a combination of standard geometric shapes such as polygons, rectangles, ellipses and quarter-ellipses. The section is created by adding or subtracting (in the case of a hole) as many basic shapes as are needed to define the composite section. The applet computes the section properties of the individual shapes and then combines them to determine the section properties of the composite section. The applet computes the area, location of the centroid, the moments of inertia, and the product of inertia about the original axes and the centroidal axes. The principal moments of inertia and the orientation of the principal axes are also computed.

The main window for the SectionProperties applet is shown in Figure 2. The section is shown in the left panel. The right panel is reserved for input, messages and results. Two methods for entering data are provided – numerical input and mouse input. To enter data numerically, students can select the shape (rectangle, ellipse, polygon, quarter ellipse) from the main menu and then use the corresponding dialog box that appears to enter data for the shape. To enter data using the mouse, the shape is selected from the pull-down combo box in the right panel of the applet. The mouse cursor changes to the corresponding shape to give a visual indication of the currently selected shape. The shape is drawn by simply clicking and dragging the mouse. The applet tracks the position of the mouse and the current x and y coordinates. These coordinates are displayed in the top left corner. The grid spacing and the snap spacing can be set from the Options menu. Sections can be added, or subtracted (as in the case of holes) to create the composite section. If an error is made in entering a shape, it can easily be deleted from the composite section by clicking on the Delete button.

Results are displayed in the list box on the top right hand side of the applet. Several computation options are provided. The applet computes and displays the x and y coordinates of the centroid, the area, moments of inertia ( $I_x$ ,  $I_y$  and  $I_{xy}$ ), and the section moduli when the Section Properties button is selected. It also displays the location of the centroid on the picture of the section. The moments of inertia about the principal axes and the angle of orientation of the principal axes with the centroidal axes are computed when the Principal Axes button is selected. Finally, when the



**Figure 2:** Section properties applet.

Mohr's Circle for Moment of Inertias option is selected the applet displays the Mohr's circle (see Figure 3). The Mohr's circle provides a convenient graphical procedure for transforming the moments of inertia  $I_x$ ,  $I_y$  and  $I_{xy}$  into the principal moments of inertia.

A useful feature of the applet is that allows students the opportunity to experiment with different types of sections and study the effect of changes in the section geometry on the properties of the section. For example, the student can compute properties of an I-shape and then add cover plates on the top and the bottom (using rectangular elements), and study the effect this has on the moment of inertia, or the student can take a rectangular section and then cut a hole in the section (by subtracting another rectangle from the larger rectangle) and create a box section and study changes in the section properties that occur when the thickness of the box section is changed. With the polygon option, a wide variety of composite sections can be created since all that is necessary are the coordinates of the vertices of the polygon.

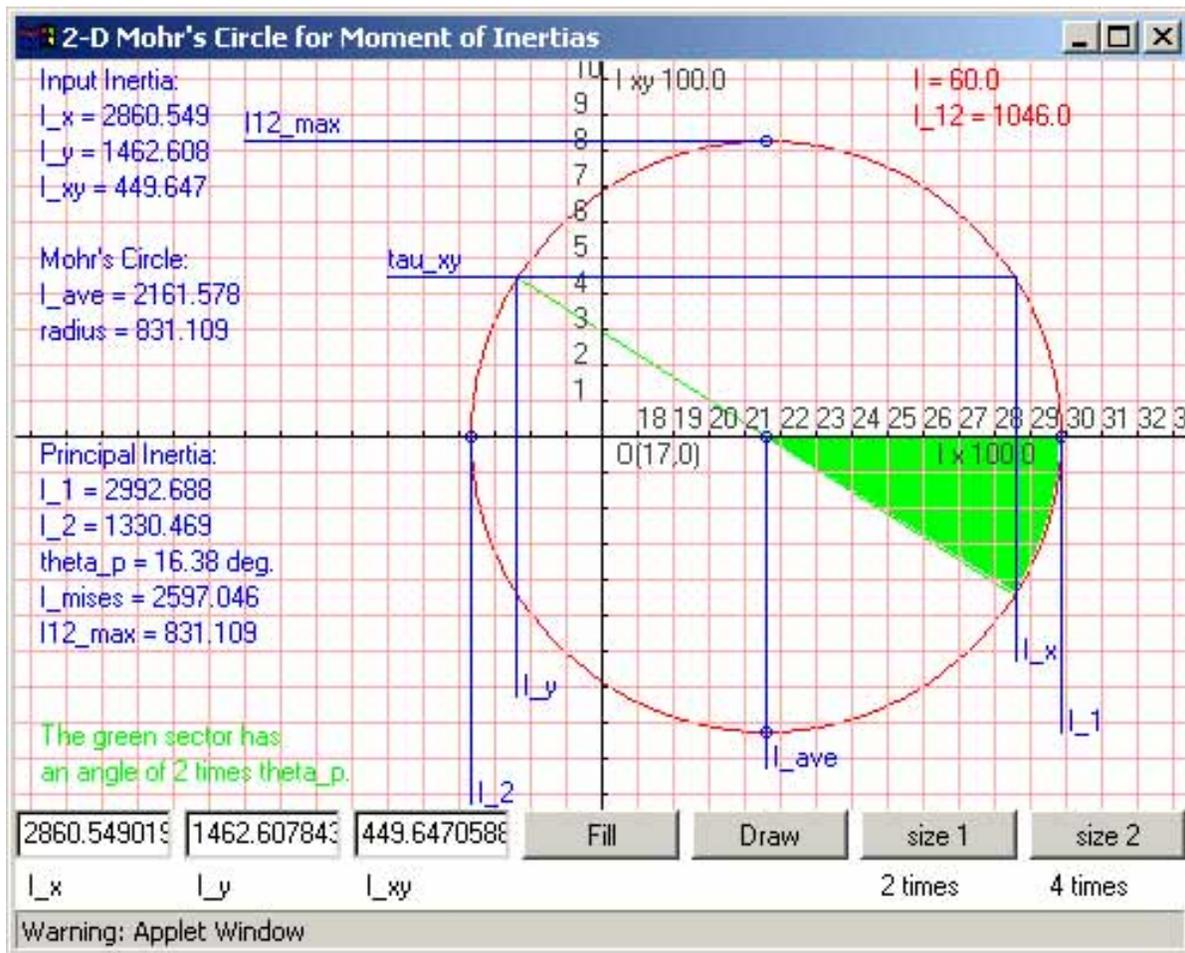
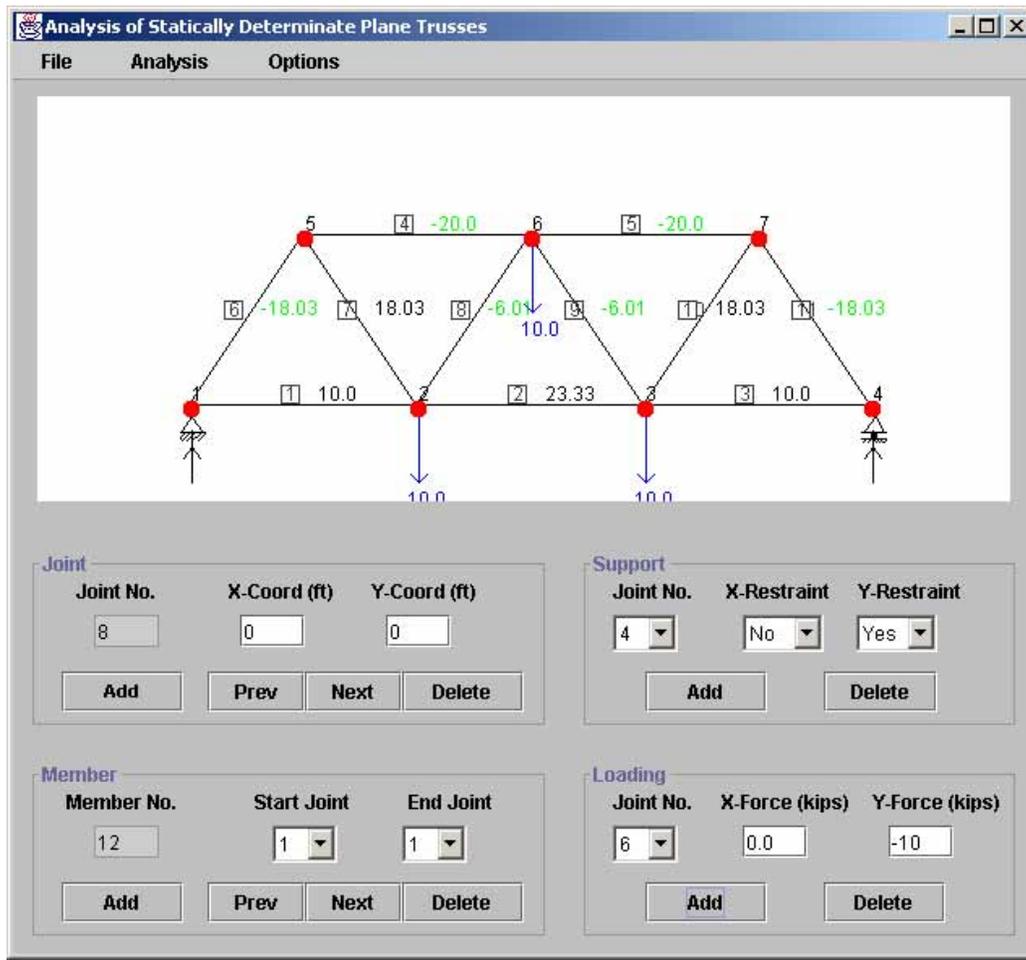


Figure 3: Mohr's circle for moments of inertia.

### Analysis of Determinate Trusses

The analysis of statically determinate plane trusses is a topic that taught in most (if not all) engineering statics courses. A truss is a structure composed of straight slender member joined at their end points by flexible connections. Trusses are widely used for supporting bridges and roofs of buildings because of their light weight and high strength. In a plane truss all of the members and applied loads line in a single plane. The analysis of a truss involves calculating the external reactions at the support and the magnitude of the axial forces (tension or compression) in all of the members of the truss. A truss is considered to be statically determinate if the member forces and support reactions can be determined by using the equations of equilibrium.

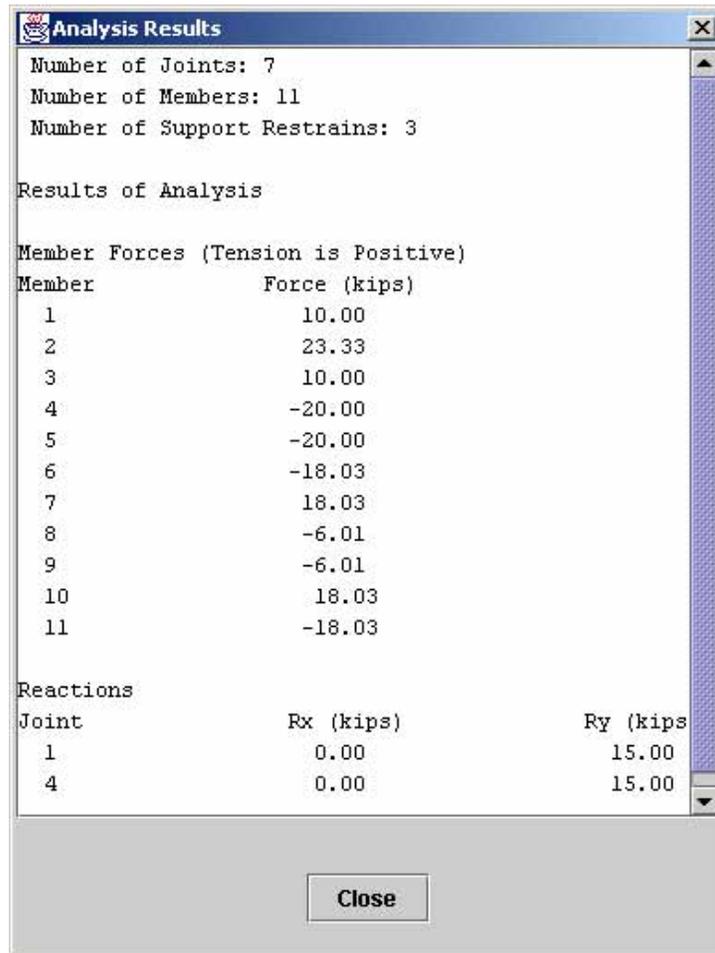
The Truss Analysis applet (see Figure 4) performs the analysis of statically determinate plane trusses. Students can specify the geometry of the truss by entering the coordinates of the joints and member incidences. Supports are added by specifying the joint number of the support and the direction of the restraint (horizontal, vertical or both). Joint loads are entered by selecting the joint and then entering the direction and magnitude of the applied load. The applet displays the



**Figure 4:** Applet for analysis of statically determinate plane trusses

joints, members and supports and applied loads. Some of the features of the applet are the following: a) the display is updated as changes are made to the truss geometry or loading thus providing students with immediate feedback, b) both metric and SI units can be used and units for each parameter can be specified in the Options menu, c) different colors are used to represent the different elements of the truss such as joints, members, loads and supports, d) extensive error checking is performed to prevent input errors, for example, as each joint is entered a check is performed to make sure that a joint with the same coordinates was not entered previously, e) before performing the analysis a check is done to ensure that the truss is stable and statically determinate, f) after the truss has been analyzed, the axial forces in the members and support reactions are shown on the truss using different colors and g) the results of the analysis are also provided in a tabular form (see Figure 5).

The Truss Analysis applet is a valuable tool since it provides students a means for checking their work, reinforces fundamental concepts learned in class, and enhances their learning experience by allowing students to experiment by building different types of trusses and studying the effect of different loads on the forces in the truss members. For example, since trusses are designed for



**Figure 5:** Results from the Determinate Plane Truss Analysis applet

several different loading conditions, it is not uncommon to have members with zero forces. The analysis of a truss is expedited if zero force members can be identified by inspection. A useful exercise is to ask students to identify zero force members in a given truss and then use the applet to verify their results.

### Experience With Use in Teaching

The instructional units have been used in several undergraduate courses taught at Virginia Tech. They were used primarily as supplementary material, reinforcing and complementing classroom and textbook instruction. For example, the BeamSpan Analysis applet was used in the undergraduate civil engineering Theory of Structures course for several semesters (approximately 150 students). An initial survey was conducted and the results of the survey clearly indicate that the response from students has been extremely positive. Based on comments received from students, several of the applets have been enhanced and modified.

Since the instructional units outlined above and the embedded applets are small and self-contained and typically address only a single concept, theory, phenomenon or application, they fit well with

the many undergraduate engineering courses and curricula. We anticipate that the availability of these instructional units over the web will lead to unsolicited integration in many engineering programs. We have already received comments from instructors who intend to integrate the units into their courses. Once the existence of these units has been publicized we expect widespread use of these instructional units and applets.

## Acknowledgements

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