Java Applets for Structural Analysis

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Abstract

A series of Web-based instructional units for the first undergraduate course in structural engineering are developed. The instructional units are centered on computer programs written in the object-oriented Java programming language. Each instructional unit consists of a series of HTML documents containing Java applets. The HTML pages have a standard format and contain the following elements: statement of educational goals, background and theory, description of applet, series of examples and exercises, suggestions for further study and exploration, supplemental information to assist other instructors, and an online evaluation form for suggestions and comments. The instructional units and the embedded applets are available over the Internet to students and instructors throughout the nation. Examples of the applets developed include: determinacy and indeterminacy of trusses and frames; shear, moment and deflection analysis of beams; analysis of determinate and indeterminate trusses; analysis of determinate and indeterminate frames; and influence lines for continuous beams. 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.

Introduction

The development of the World Wide Web (WWW) has led to unprecedented growth in access to information over the Internet. In the last five years, educational institutions have realized the importance of the web as a tool for education. The web offers many advantages including ease of use, quick access and low cost. The web-based learning environment is available without the limitations of time or location. Information on the web can be accessed from any computer platform since it is hardware and software independent. Another important advantage is global accessibility. Web documents are accessible from any computer connected to the Internet. The web-based learning environment is also flexible in that it allows students to control their own learning pace. Another advantage of the web-based learning environment is that there are no distribution problems. Students no longer need to get software through CD-ROMs or floppy disks. Also, since there is only one copy of the learning module on the web server it can easily be updated.

A major disadvantage of the web was that most documents on the web used HyperText Markup Language (HTML). HTML documents consist mainly of text with some graphics and are effective for one-way distribution of information but are static and insufficient for providing an interactive

environment essential for learning.

The Java Language

Although several technologies have been developed for delivering interactive content on the web such as Common Gateway Interface, JavaScript, Visual Basic Script, Shockwave and QuickTime, the most exciting of these is the Java programming language developed by Sun Microsystems. The most important reason why Java is so well suited for use on the Internet is that it is platform and operating system independent - both at the source and the binary level. The some code can be downloaded over the network and executed on any machine that has a Java capable browser. Also, Java applications can be embedded in HTML documents where they are called applets and can be run on any computer as long as the client machine has a Java enabled browser. With Java it is now possible to write highly interactive graphical applications that are platform independent and are delivered over the web.

The Java language is an object-oriented language developed by Sun Microsystems and is modeled after the popular C++ programming language. Some of the features of the Java language include the following:
Object-Oriented: Java is an object-oriented language and has all the benefits of other object-oriented programming languages such as reusability of code, extensibility, encapsulation and inheritance. Most of Java's object-oriented features are inherited from C++. Although the syntax and structure of Java is similar to C++, many of the complex elements of C++ that have caused programmers difficulty or have been a source of frequent bugs have been removed or streamlined, thus making the language simpler.

Platform Independent: Java applets and applications are platform independent, that is, a Java program can run on any computer that has a suitable interpreter, such as a Java-capable browser. This is possible because the Java compiler generates an architecturally neutral object file containing byte-code instructions and not binaries. Byte-code instructions are translated into native machine code at runtime by the Java interpreter. Also, the Java language is the same on all systems. Thus, it is not necessary to produce multiple versions of an application. The same application runs on all hardware platforms. This makes Java an ideally suited language for Internet applications.

Portable: In addition to its platform independent features, Java has several other features that enhance portability. Unlike C++, in which the sizes of the fundamental data types such as integers and floats, are implementation dependent, Java specifies the same standard sizes for the fundamental data types regardless of hardware. Also, the Java class libraries define portable interfaces for most platforms. Once an application has been ported to a single machine, it is no longer necessary to modify it to run on another machine.

Robust: Although Java is an interpreted language it does not have some of the performance problems traditionally associated with interpreted languages. The Java compiler converts source code to machine independent byte-code. This byte-code is very close to machine code and the process of interpreting byte-code to machine code for a specific platform is very efficient. Java also has built-in multithreading capability and Java uses processor idle time to perform garbage collection and other system maintenance tasks.

Simply and Easy: Java is a simple and easy language. Since Java is fashioned after C++ it is familiar to most programmers and requires less time to learn. Many of the poorly understood and problematic elements of C++ such as pointers and pointer arithmetic, multiple inheritance, operator overloading, coercion of data types, header files and the preprocessor, have been eliminated. Java has embedded automatic memory management thus eliminating much of the programming effort associated with memory management. Java also has a powerful set of class libraries with provide much of the functionality needed to develop applications.

Format Of Instructional Units

A series of web-based instructional units for the first undergraduate course in structural engineering have been developed. These instructional units are centered on computer programs written in Java. Each instructional unit consists of a series of web documents containing embedded Java applets. To facilitate the learning process, the instructional units have a standard format. Each instructional unit has the following elements: an introduction, background, instructions, examples, exercises and a feedback form. The introduction page provides a description of the subject matter and fundamental concepts. The background page provides the necessary theoretical background, lists the equations used and provides the relevant theory. The instructions page contains detailed instructions for using the applet. The examples page provides example problems and the results obtained from the applet. The exercises page provides a series of exercises to assist students in exploring the concepts being presented. The online evaluation form is designed to access attitudes of users and the effectiveness of the instructional unit.

All applets run in their own separate window rather than within the browser window. This makes for easier navigation since students do not have to move back and forth between web documents and the applet. Thus, students can access information such as the instructions for using the applet, example problems and exercises, and still have the applet running. The applets are designed to have a significant impact on students by providing them with additional information and tools that facilitate their understanding of the material over a medium that allows independent learning at an individual pace. They make extensive use of graphics and allow for significant interaction.

Description of Applets

Brief descriptions of a few of the applets are provided in this section. The reader is encouraged to visit the web site http://structures1.ce.vt.edu/Applets for additional details.

Determinacy, Indeterminacy and Stability of Truss and Frames

The concepts of stability, determinacy and indeterminacy are important in structural analysis. Since different techniques are used analyze statically determinate versus statically indeterminate structures it is important that students be able to identify whether a structure is stable, determinate or indeterminate. The statical classification of a structure depends on the number of support reactions, number of equilibrium equations, number of members, and the arrangement of the members.

The Truss Determinacy applet allows students to experiment with the statical classification of

trusses. The applet displays a series of trusses and for each truss students are asked to input the number of members, number of joints, number of unknowns and decide whether the truss is unstable, determinate, or indeterminate. The applet computes the degree of indeterminacy and checks the answers provided by students. Students then have the opportunity to correct their answers or view the correct answers. The truss examples are stored as a series of image files so the applet can be customized by simply changing these files. Figure 1 shows the Truss determinacy applet.

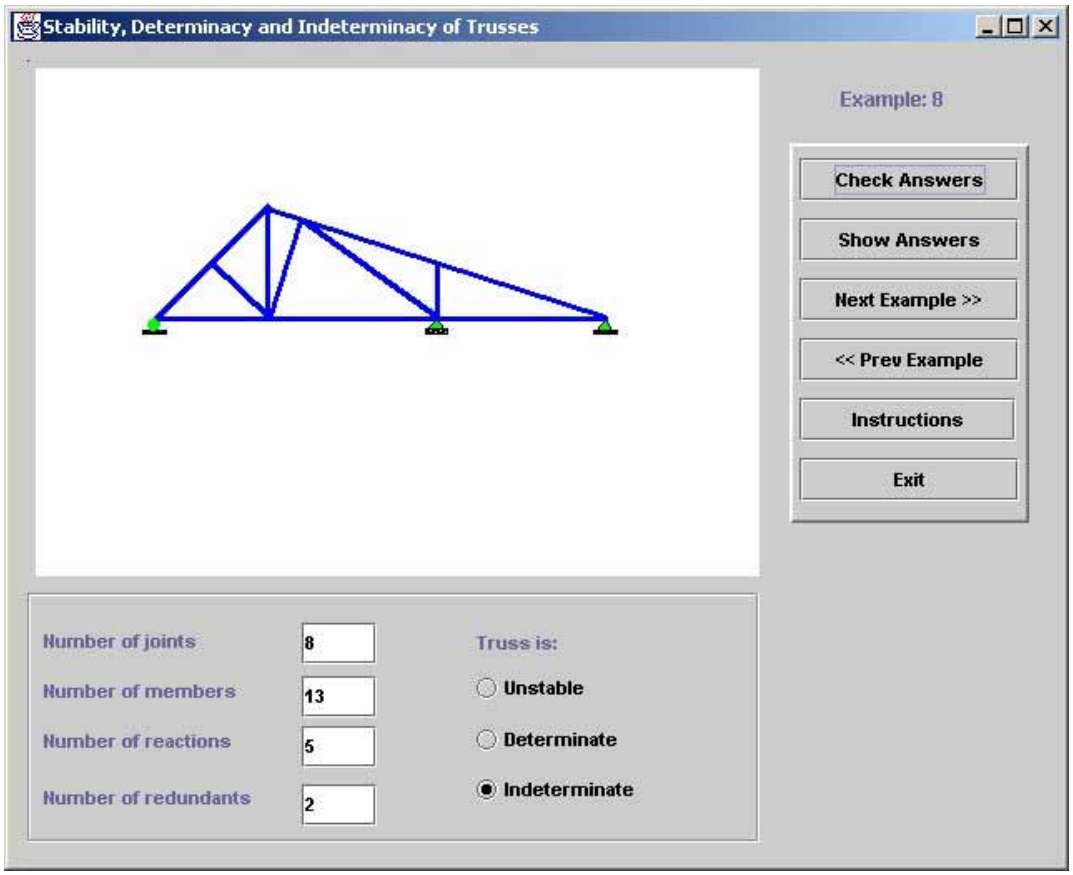

Figure 1: Truss Determinacy Applet

The Frame Determinacy Applet (see Figure 2) is similar to the Truss Determinacy applet and has many of the same features. The applet displays a series of plane frames and for each frame, the student is required to input the number of members, number of joints, and number of unknown reactions, number of degrees of freedom, and the degree of internal, external and total indeterminacy. The program checks the answers provided by students. As with the Truss Determinacy applet, students are provided with an opportunity to correct their answers or view the correct solution.

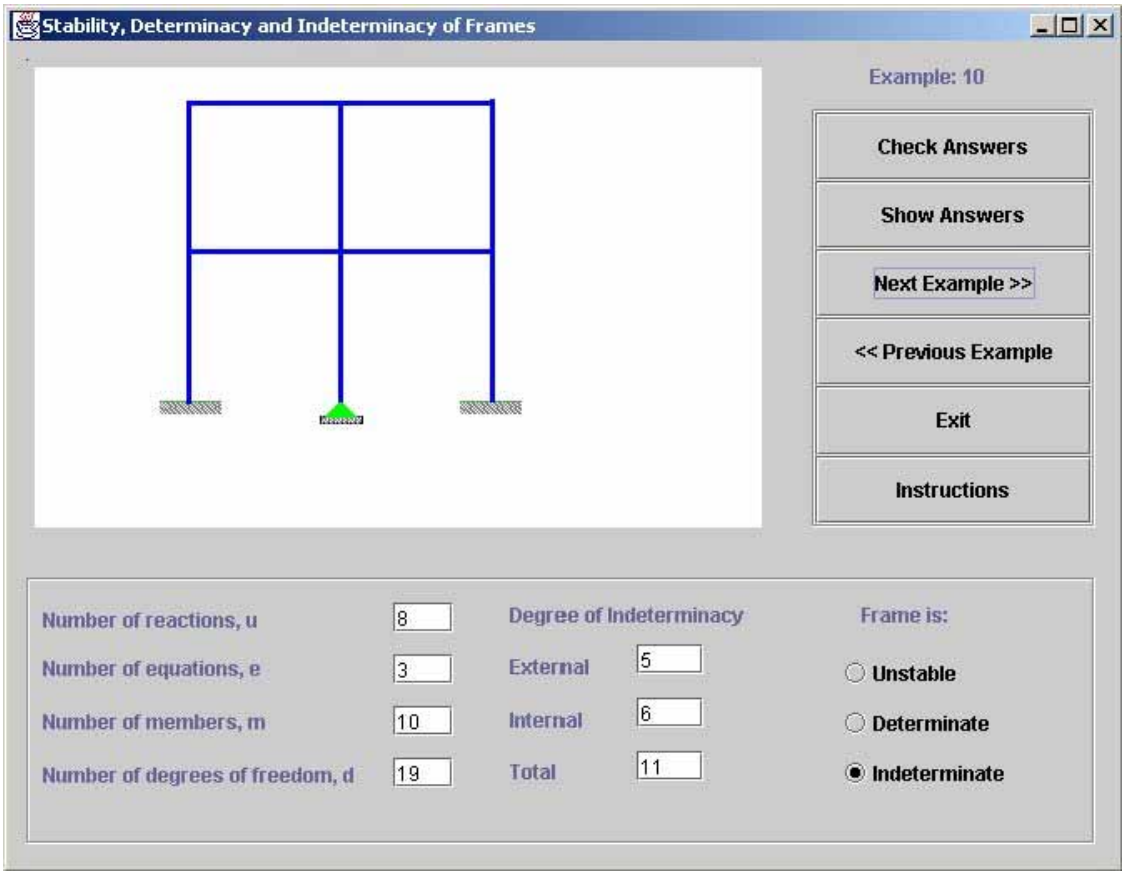

Figure 2: Frame Determinacy Applet

Analysis of Statically Determinate and Indeterminate Trusses

The analysis of trusses is a topic that taught in most undergraduate structural analysis 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 lie 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 Determinate Truss Analysis applet shown in Figure 3 performs the analysis of statically determinate plane trusses. The geometry of the truss is specified by entering joints coordinates and member incidences. Supports are entered by giving the joint number 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 joints, members and supports and applied loads as they are entered. The applets uses a matrix analysis approach to compute support reactions and the axial forces (tension or compression) in the members of the truss. These results are displayed on the truss and are also available in the from of a table.

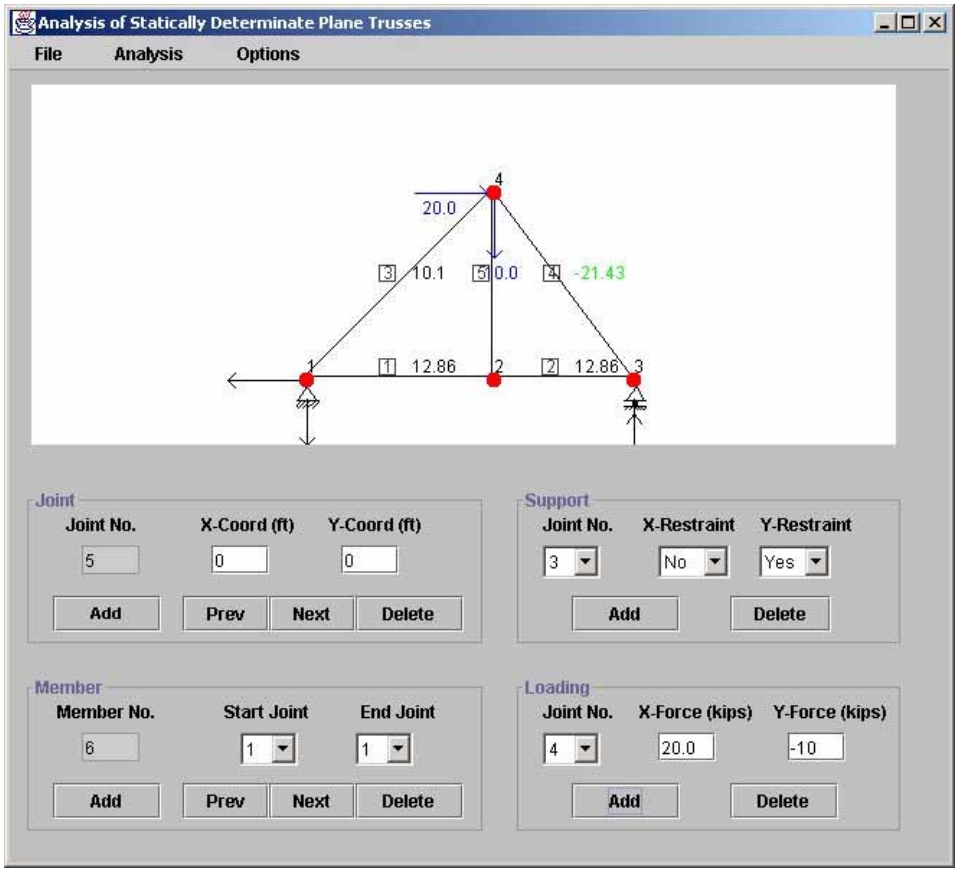

Figure 3: Java applet for the analysis of statically determinate plate trusses.

The Determinate Truss Analysis applet is a valuable tool for students 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 without having to perform tedious and time consuming computations. For example, since trusses are designed for 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 for students to identify zero force members in a given truss and then use the applet to verify their results.

The Indeterminate Truss Analysis applet shown in Figure 4 performs the analysis of statically indeterminate plane trusses. This applet is similar to the determinate truss analysis applet, except for the fact that the truss to be analyzed can be statically indeterminate. Since the analysis of indeterminate trusses involves the area of the truss members and material properties, the indeterminate truss analysis applet has additional input fields for the area and modulus of elasticity. The applet uses the stiffness method to compute support reactions and axial forces in the truss members. This applet has many of the same features as the determinate truss analysis applet. The main window displays the truss geometry and forces acting on the truss. The results window displays the results of the analysis.

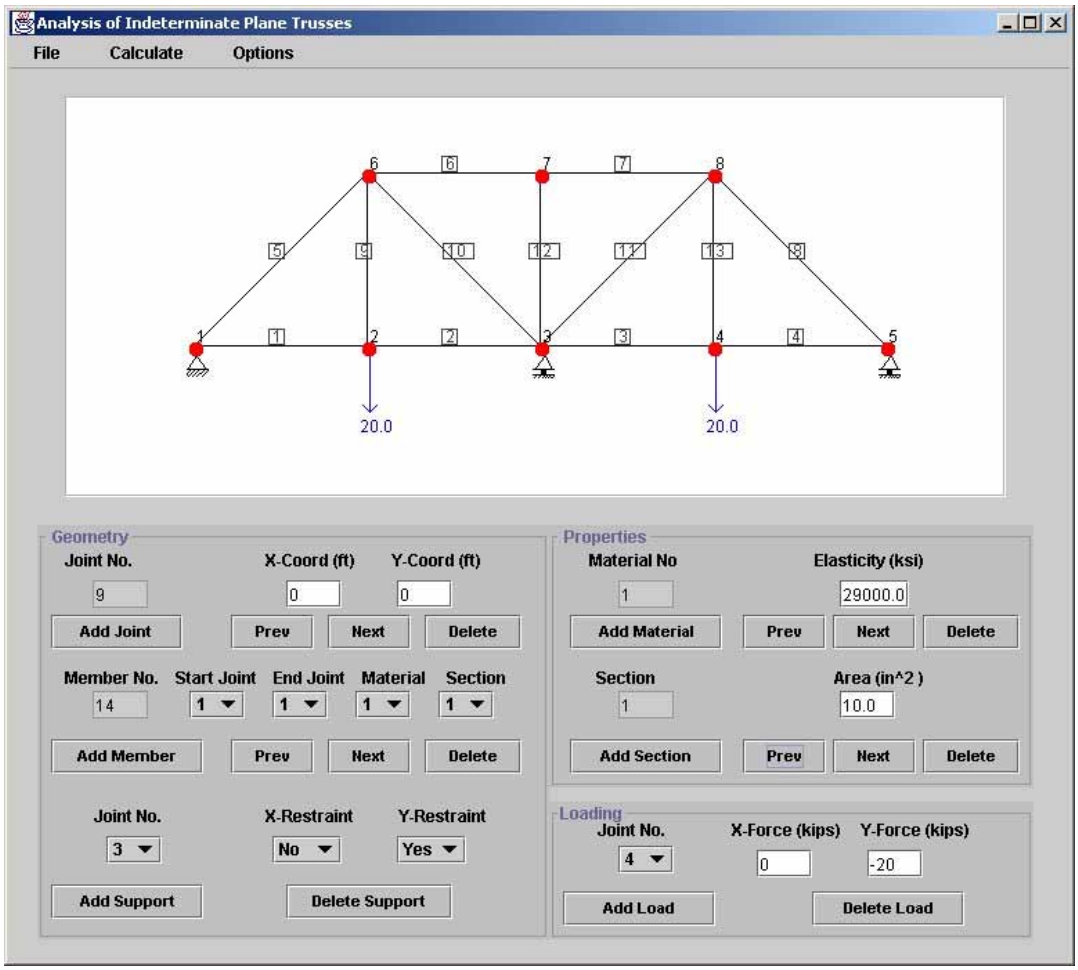

Figure 4: Indeterminate Plane Truss Analysis Applet

Some of the features common to both the determinate and indeterminate truss analysis applets 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, 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, 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.

Influence Lines for Continuous Beams

For structures subjected to moving loads, such as highway bridges and runway cranes, the design

of each member of the structure must be based on the maximum forces that are developed as the load moves across the structure. The analysis of structures under moving loads involves determining the positions of the load at which the response of interest (e.g., reaction, shear force, or bending moment) becomes maximum and computing the maximum value of the response. A valuable tool for the analysis and design of structures subjected to moving loads is the influence line. The properties of influence lines are discussed in most introductory structural analysis textbooks [1,2]. An influence line is a graph of a response quantity as a function of the position of a unit load moving across the structure. The ordinate of the influence line at any point is the magnitude of response due to a single unit load acting at that point.

The Influence Line applet (see Figure 6) draws influence lines for determinate and indeterminate beams. The program divides each span of the given beam into a series of user specified points. At each point a unit load is placed and the response is computed using the matrix displacement method. This process is repeated for each point along the beam and the results are saved. After the program has completed the analysis, the influence line of the beam is drawn.

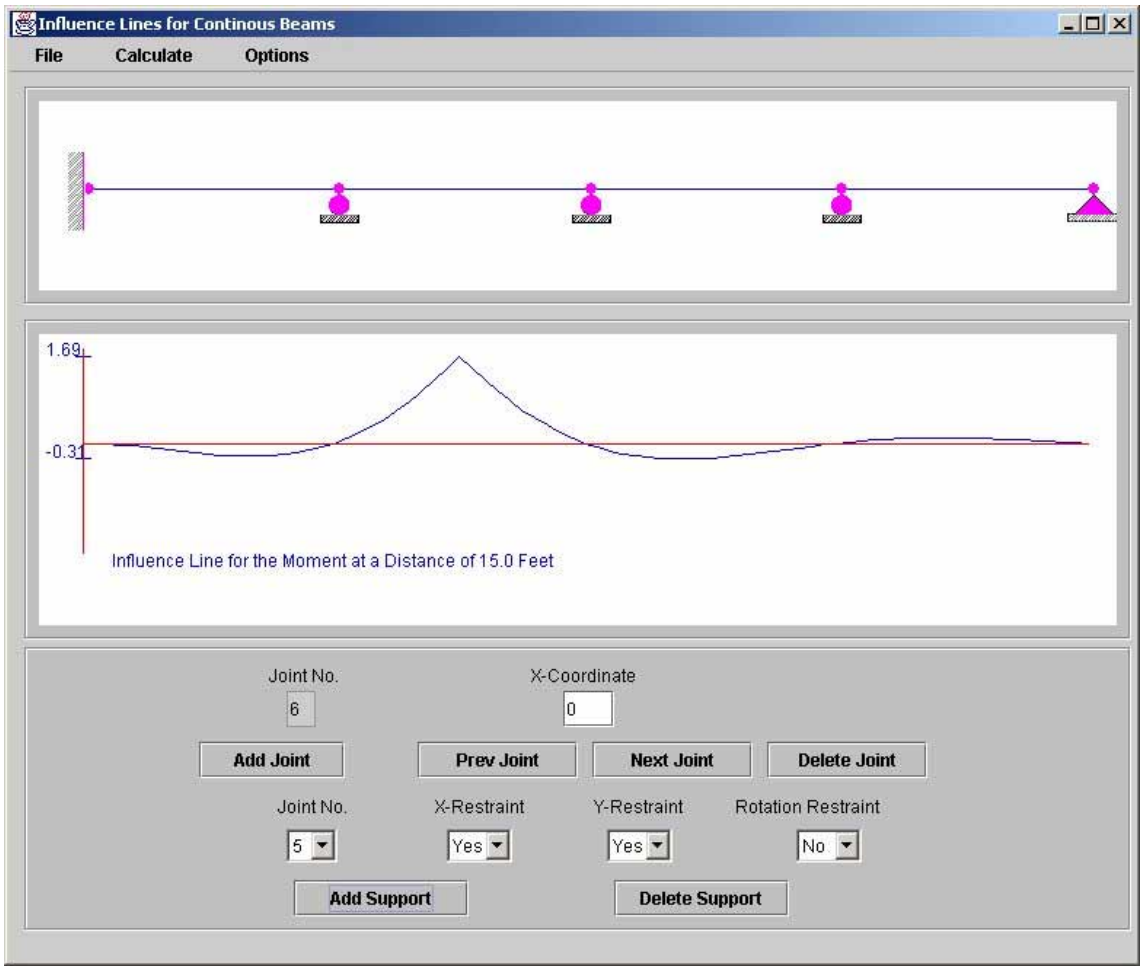

Figure 5: Applet for drawing influence lines for continuous beams

The user defines the beam geometry by specifying the x-coordinate of each joint, and the support conditions. The applet graphically displays the beam geometry. The program can draw influence lines for support reaction, shear, and bending moment at user-specified locations. Figure 6 shows the main frame of the applet. The applet employs two canvas areas, one for displaying the beam and the other for displaying the influence diagram. In addition to the two canvases, a panel of buttons and a menu bar are also available for entering commands and data. The results of the computations can also be displayed in tabular form.

Other Structural Engineering Applets

In addition to the applets described a number of other applets of interest to structural engineers have been developed. These are available from the web site. A brief description of these applets follows:

Beam Span Analysis: This applet calculates shear, moment and deflections at specified intervals along a single span beam and also draws the shear, moment and deflection diagram. The types of beams considered include cantilever beams, simply supported beams, propped cantilever beams, and beams with both ends fixed. The load that can be applied to the beam include distributed loads, concentrated loads, linearly varying loads and applied moments. Additional information about this applet is presented in [3].

Section Properties of Composite Sections: This applet computes section properties of 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 need to define the composite section. The applet computes the area, location of the centroid, moments of inertia and the product of inertia. The applet also computes the principal moment of inertia. Details of this applet are given in [3].

Analysis of Determinate and Indeterminate Plane Frames and Continuous Beams: The Determinate Plane Frame Analysis applet computes support reactions and member forces in a statically determinate frame. Input to applet consists of the coordinates of the joints, member incidences, support conditions and applied loads. The loads that can be applied to the frame include joint loads and member loads. The applet uses matrix methods to compute support reactions and internal forces in the members (axial force, shear force and bending moment). The Indeterminate Plane Frame Analysis applet is similar to the determinate plane frame analysis applet. However for this applet additional input such as section and material properties are required for the analysis. The analysis is done using the stiffness method. The Continuous Beam Analysis applet is a special case of the Indeterminate Analysis applet in which all members are horizontal and joints can only undergo rotations but not translations.

Cables and Arches: The Cable applet performs the analysis of cables subjected to uniformly loads. It computes the tension in the cable at various points and the force in the hangers supporting the girder. The Arch applet provides insight into how arches transmit loads. It performs the analysis of a three-hinged arch. The third hinge is located at the crown of the arch. The applet computes the reactions at the support and the internal hinge reactions.

Experience With Use In The Classroom

At present we have limited experience with the use instructional units and the embedded applets in

the classroom since many of them were under development. Some of the applets have been used for several semesters in the undergraduate introductory course on structural analysis taught at Virginia Tech. They were primarily used as supplementary material reinforcing and complementing classroom and textbook material. An initial survey was conducted and the results of the survey clearly indicate that the response from students has been extremely positive. Several of the applets have been modified and enhanced based on input received from students. Many of the applets are quite useful for checking answers to homework problems. For example, the continuous beam analysis applet is well suited for checking results obtained using the slope deflection method or the moment distribution method – two topics that are taught in most (if not all) introductory structural analysis courses.

Since the instructional units are small and self-contained and typically address a singly topic they fit well with many undergraduate introductory structural analysis courses. We anticipate that the availability of these applets over the web will lead to their integration in many engineering programs. Once the existence of these units has been publicized we expect widespread use of these instructional units and applets.

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1.2 Appropriate Computer usage for Structural Analysis. The rewards of using computers for structural design are many. Today's buildings and bridges are larger and more intricate than ever before imagined possible in the pre-computer era.Â Java restricts the connections that an applet can make and can only connect back to the same web server from where it originated. For this reason, the server. j ava class must be run on the same web server from which the applet originates. When running the programs as applications, however, connections can be made to any server with a valid host name. -31