

Java Applet for Teaching Influence Line Analysis

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Introduction

Educational institutions have come to realize the importance of interactive learning and a multitude of interactive educational software is now available, The Internet has become an integral part of education, providing an excellent environment for hosting interactive learning. The development of the World Wide Web (WWW) has led to unprecedented growth in access to information over the Internet. The web offers many advantages including ease of use, quick access and low cost. An important advantage of the web is global accessibility. Web documents are accessible from any computer connected to the Internet. The web-based learning environment is flexible in that it allows students to control their own learning pace. A major disadvantage of the web was that most documents on the web use the HyperText Markup Language (HTML). HTML documents consist mainly of text with graphics and are effective for one-way distribution of information but are static and insufficient for providing an interactive environment essential for learning.

Some of the technologies for delivering interactive content on the web include Common Gateway Interface, JavaScript, Visual Basic Script, Shockwave, QuickTime and Java. The most exciting of these is the Java programming language developed by Sun Microsystems. Java is an object-oriented language modeled after the popular C++ programming language. It has all of the benefits of other object-oriented programming languages such as reusability of code, extensibility, encapsulation and inheritance. 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. 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. 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 are implementation dependent, Java specifies the same standard sizes for the fundamental data types regardless of hardware. Thus, it is not necessary to produce multiple versions of an application. The same code can be downloaded over the network and executed on any machine that has a Java capable browser. Java also has a powerful set of class libraries with provide much of the functionality needed to develop applications. Java applications can be embedded in HTML (web) documents where they are called applets. With Java it is now possible to write highly interactive graphical applications that are platform independent and are delivered over the web.

Influence Lines

Many structures are subjected to moving loads. Examples of such structures include highway and railway bridges, industrial buildings with overhead traveling cranes, and frames supporting conveyers. The internal forces in these structures vary not only with the magnitude of the loads but also with the

position of the loads. Since each member of a structure must be designed to withstand the most severe conditions that can possibly develop during the lifetime of the structure, the design of structures subjected to moving loads must be based on the maximum forces that are developed as the load moves across the structure. The analysis of such structures involves the determination of the positions of the loads that produce the maximum response (e.g., reaction, shear force, or bending moment) in the member and the computation of the maximum value of the response. It is important to note that the critical positions for placing moving loads will not be the same for each member. Also, the placement of loads will be different for different responses. Although in some cases it is possible by inspection to determine where to place the loads to give the maximum forces, for most cases it is necessary to use specialized tools and diagrams to determine the placement of the loads.

The most useful tool for the analysis of structures subjected to moving loads is the influence line. The great German engineer Professor E. Winkler of Berlin developed the theory and use of influence lines in 1867 (Kinney, 1957). An influence line shows graphically how the movement of a unit load across a structure influences some response of the structure. Responses that may be represented include: support reactions; shear forces, bending moments and displacements. The ordinate of the influence line at any point is the magnitude of the response due to a single unit load acting at that point. The shape of the influence line is very useful in locating the position of a load that produces the maximum value of the response. Different loading positions produce maximum values of shear, moment or reaction at a point, thus separate influence lines are needed for each type of response. Although influence lines are always drawn for a unit value of the moving load they can be used to determine the effect of several concentrated and distributed loads acting on the structure by applying the principle of superposition. Properties of influence lines and their application in the design of structures are discussed in structural analysis textbooks (Hibbeler, 1999; Kassamali, 1990; Kennedy and Madugula, 1990).

Influence Line Analysis Applet

An interactive web-based instructional unit for teaching the fundamental concepts of influence line analysis has been developed. The instructional unit is centered on a Java applet. An applet is a computer program written in the platform independent object-oriented Java programming language embedded in web pages and is available to all students and instructors via the Internet. The influence line analysis applet computes the response of statically determinate and indeterminate beams at each point as a unit load moves across the beam. The matrix displacement method is used to analyze the structure. The applet computes influence lines for reaction, shear force and bending moments and displays these graphically. The applet makes extensive use of graphics. The accompanying web pages provide the background on influence line analysis, instructions for using the applet, example problems, and exercises.

The Influence Line Analysis applet draws influence lines for determinate and indeterminate beams. The program can draw influence lines for support reaction, shear, and bending moment at user-specified locations. Each span of the given beam is divided into a series of user specified points. At each point a unit load is placed and the response is computed. 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.

Program Interface

Figure 1 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, an input panel containing buttons, a text field, and several list boxes is provided for entering the beam geometry. A menu bar is also available for entering commands. The beam is displayed in the upper canvas area. The influence line for the selected response (in this case the moment at a distance of 15 ft from the left support) is displayed in the lower canvas area.

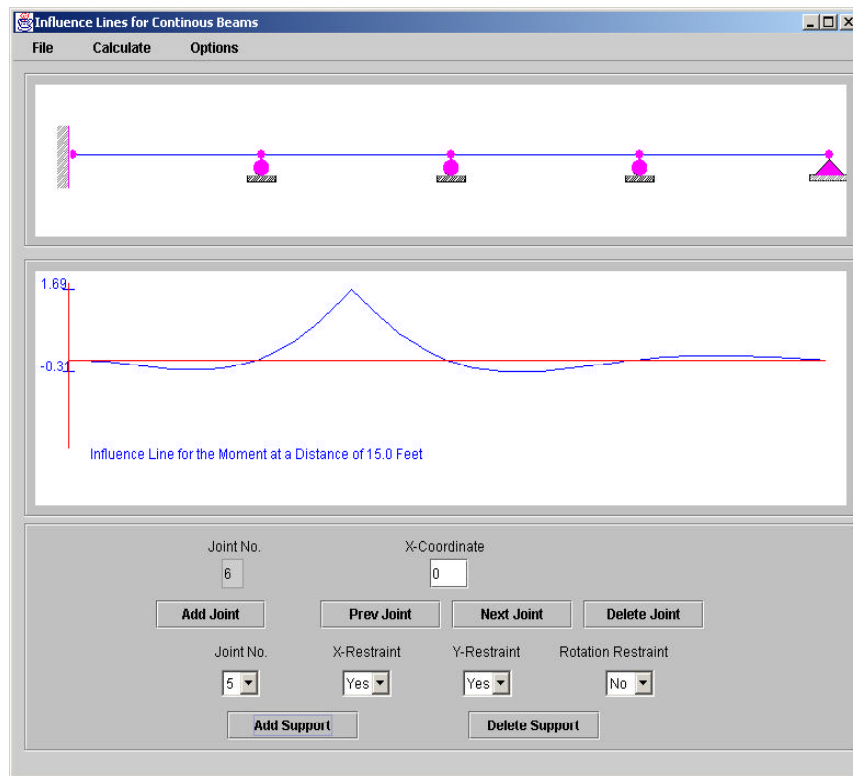


Figure 1: Applet for drawing influence lines for continuous beams.

Beam geometry is defined by entering the x-coordinate for each joint in the text input field and the corresponding joint constraints. There are three constraints at each joint: horizontal displacement, vertical displacement and rotation. These are selected using list boxes. The applet continuously updates the image of the beam displayed in the upper canvas area as joints and supports are entered, thus providing constant visual feedback, and ensuring that errors in entering beam model are corrected before running the analysis.

The menu bar contains a File menu, a Calculate menu and an Options menu. The File menu contains two menu items, New and Exit. When the New menu item is selected, the beam and existing input data are cleared. Selecting the Exit selection menu results in exiting the entire program. The Calculate menu item contains the Select Response menu item. When this menu item is selected the Select Response dialog box shown in Figure 2 is displayed. The desired response and the location of this response can be entered in this dialog box. The applet computes influence lines for three types of

responses: a) reaction at a support, b) shear force at any point on the beam, and c) bending moment at any point on the beam. Several checks are performed to ensure accuracy of the input data. For example, if the response quantity of interest is the reaction at a support, the applet checks that the distance entered in the input field does indeed correspond to the location of a support in the beam. All distances for shear and moment are checked to ensure that these values do indeed lie within the beam.

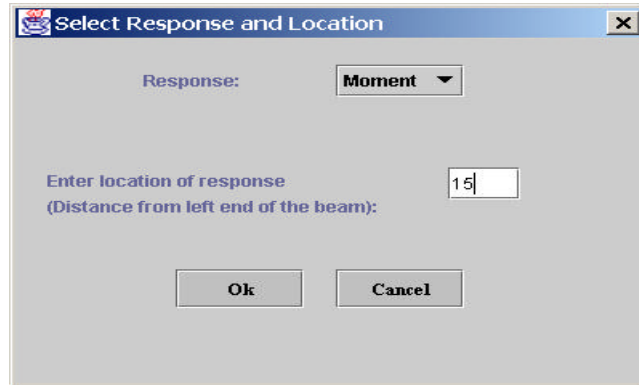


Figure 2. Response Selection Dialog box.

The Options pull down menu contains two menu items. The Select Units and Scale menu item displays the dialog box shown in Figure 3. This dialog box allows the user to select the system of units (SI or metric), the value of the maximum x-coordinate (which controls the graphical display of the beam model and influence line diagram), and the number of intervals at which the unit load is placed on each span.

The second menu item under the Options Selection is the Show Output menu item. This opens a window containing a table of the ordinates of the influence line versus distance from the left support. An example of this table is shown in Figure 4. This table is useful for computing the response of the beam for various types of loading such as a standard AASHTO truck moving across the beam.

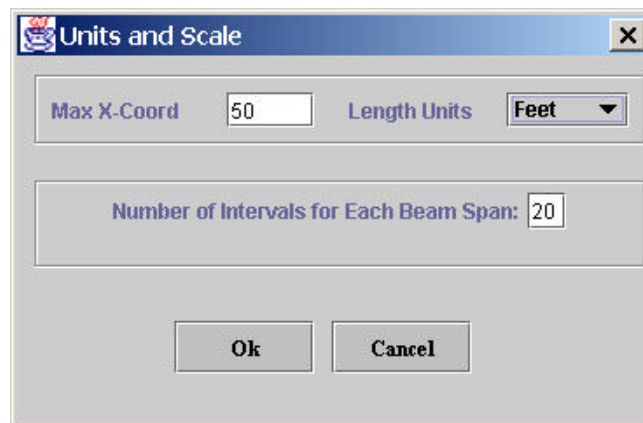


Figure 3. Units and Scale Dialog box.

Distance (Feet)	Moment
0.00	0.00000
1.00	-0.01531
2.00	-0.05443
3.00	-0.10716
4.00	-0.16330
5.00	-0.21263
6.00	-0.24495
7.00	-0.25005
8.00	-0.21773
9.00	-0.13778

Figure 4. Coordinates of Influence Line.

The Influence Line Analysis applet runs in its 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 applet is 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. It makes extensive use of graphics and allows for significant interaction between the applet and the student. Some of the features of the Influence Line Analysis applet include: a) the display is updated as changes are made to the beam geometry thus providing students with immediate feedback, b) both the metric and SI system of units can be used, c) different colors are used to represent the different elements of the beam such as joints, members, 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 beam is stable, and f) the results of the analysis are provided in a tabular form.

Computational Procedure

The influence line applet can analyze both statically determinate and indeterminate beams. Each span of the beam is divided into a number of user-specified intervals. A unit load is placed at each of these points along the beam and the beam is analyzed. Support reactions are computed and stored in an array. The applet then computes the response (shear, moment or reaction) at the current location of the unit load and saves the result. The unit load is then applied to the next point on the beam and the process is repeated. After the analysis is completed for all of the points along the beam, the influence line of the beam is drawn.

The beam is analyzed using the matrix displacement method (Hibbeler, 1999; Kassamali, 1990; Rossow, 1996). Element stiffness matrices are generated for each span. These are then combined by imposing conditions of compatibility to obtain the global stiffness matrix for the beam. The global stiffness matrix relates the external forces and the joint displacements. For the purposes of computing influence lines, the only external force on the system is the unit load acting at a given distance along

the span. Joint forces are obtained by computing fixed end moments and reactions resulting from the application of this unit load. Joint displacements are computed by solving the resulting system of equations using Gauss elimination. Once joint displacements have been determined, support reactions and element forces are computed.

As a unit load is placed along the beam at the specified points, the matrix displacement calculations described above, are performed for each point on the beam and the response at each point is computed. The results of these computations are stored in an array and then plotted by the applet, producing the influence lines.

Program Classes

The applet was developed using the object-oriented approach. Classes were developed for the various elements of the application. The applet contains two distinct types of classes of classes: a) structural classes, and b) program interface classes. Structural classes are classes for representing the structural model. The structural classes developed include the Support, Joint, Member, Value, and Analysis classes. A brief description of these classes is given in Table 1. All of the computations are performed in the Analysis class. This class contains several methods. A brief description of the methods in the Analysis class is given in Table 2. The interface classes developed include the ManyLineLabel, Dialogbox, OutputFrame, Option, IntTextField, DoubleTextField, InfluenceLineApplet and InfluenceLineFrame class.

Table 1. Structural Class Contained in the Influence Line Applet

Class	Description
Analysis	All the analysis of the structure is performed here.
Member	Represents members in the structure. This class contains data members for storing information about each member including span length, starting and ending x-coordinates of the member.
Joint	Represents a joint in the structure. This class contains data members for storing joint information such as the x-coordinate of the joint.
Support	Represents supported joints in the structure. Contains support data including information regarding releases.
Value	Keeps track of analysis results. Data members of this class include an x-coordinate and a response value.

Example Problems and Verification

The capabilities of the applet are demonstrated by means of several examples. Figure 5 shows the influence line for shear at a distance of 4 ft from the left support for a statically determinate beam with an overhang. The influence line for moment at the center of an interior span of a three span continuous beam is shown in Figure 1. Figure 6 shows the influence line for the reaction at the center support for a four span continuous beam.

Table 2. Methods in the Analysis Class

Function	Description
CheckMaxCoordinate()	Computes the maximum x-coordinate. This value is needed for scaling the influence and beam diagrams.
checkStability()	Checks stability of the structure and displays an error message if the structure is unstable.
CalculateTotalRestrains()	Determines the total number of restraints in the structure.
ElementStiffness()	Generates element stiffness matrices
Gauss()	Solves for joint displacements using Gauss elimination.
generateMCode()	Generates a matrix that relates member displacements to structure displacements.
MemberEndForces()	Computes member end forces.
MomentInfluence()	Determines the ordinate of the influence diagram for bending moment.
Loading()	Checks for presence of unit load on a member and computes fixed end forces
ReactionInfluence()	Computes the ordinate of the influence diagram for support reaction.
setUpMemberVector()	Initializes member and joint vectors. These vectors are used to store member and joint data.
ShearInfluence()	Determines the value of the ordinate of the influence diagram for shear force.
Stiffness()	Computes the global stiffness matrix.
storeDisplacements()	Saves the computed joint displacements obtained after solving the system of equations.

The accuracy of the results obtained from the applet was verified by comparing the results obtained from the program for a number of example programs with results from several other sources such as Hibbeler (1995), Barker and Puckett (1997), and AISC (1993).

Use In Teaching

Influence line analysis is a topic taught at the undergraduate level in introductory structural analysis courses. Most civil engineering departments offer a course on structural analysis and this course is typically required of all undergraduates. Influence line analysis is also used in steel, concrete, and bridge design courses. Students have difficulty in understanding the basic concepts of influence line analysis since most of their experience thus far has been limited to static loads rather than moving loads. However, the study of influence lines can immeasurably increase students' knowledge of what happens to a structure under different loading conditions.

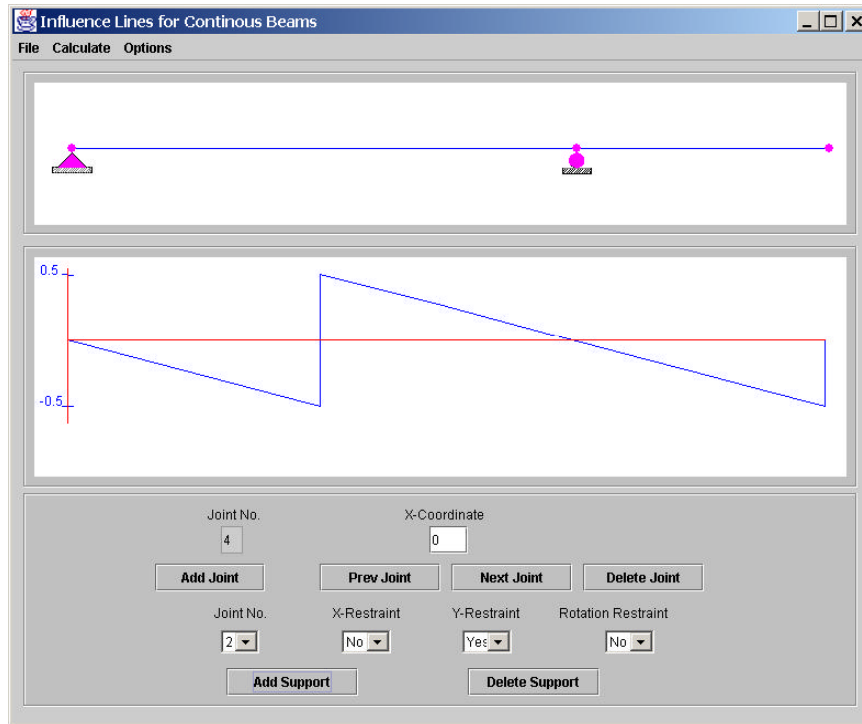


Figure 5. Influence line for shear for a determinate beam with an overhang.

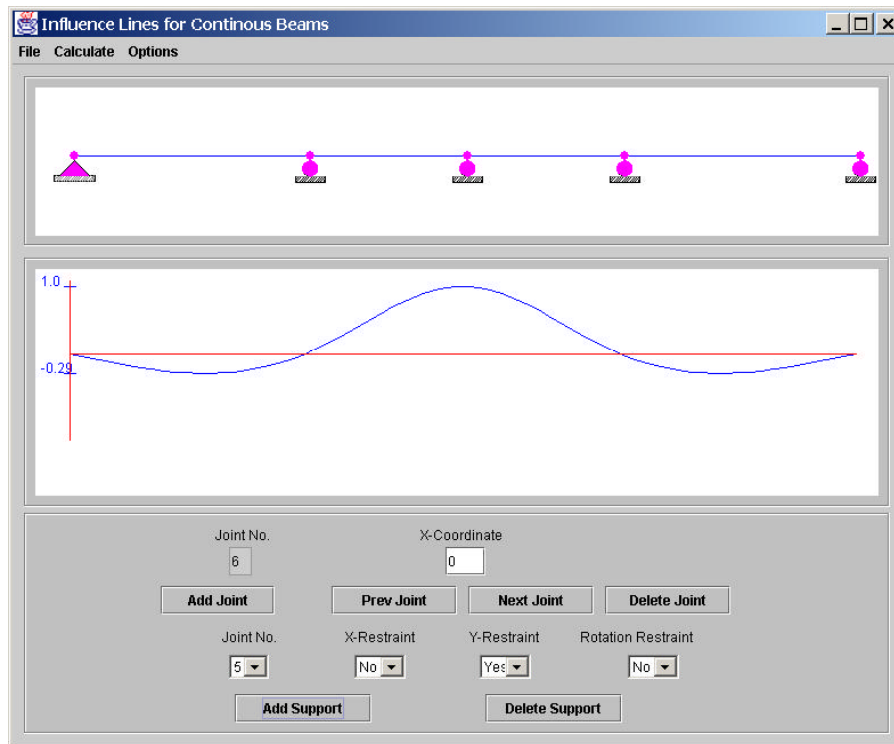


Figure 6. Influence line for reaction at the center support for a four span continuous beam.

The influence line applet and several other structural analysis applets (Rojiani, et al, 2000; Rojiani and Schottler, 2000) have been used extensively in courses taught at Virginia. The influence line applet has been used primarily in CEE 3404, Theory of Structures. This is an introductory structural analysis course. In this course, students are first taught the fundamentals of influence line analysis and are required to determine influence lines for statically determinate beams using hand calculations. They are also required to use influence lines to compute responses due to uniformly distributed loads, a series of concentrated loads, and to determine the location of these loads that cause the maximum response (reaction, shear, or bending moment) in the beam. Students are also taught to use the Müller-Breslau approach to draw qualitative influence lines for statically indeterminate beams. Students are then introduced to the influence line applet. They use the applet to check the results of their hand calculations for statically determinate beams. They also use the applet to obtain quantitative influence lines for statically indeterminate beams and compare these to the qualitative influence lines obtained from the Müller-Breslau approach.

Several methods were used to assess the effectiveness of the applets in improving student learning. An online survey was conducted. Every student who used the applet was encouraged to fill out this online survey. At the end of the course, students were asked to fill out a written survey on their use of the structural analysis applets. A third form of assessment involved personal interviews with a smaller group of students. Also, since the applets were located on a Web server, the use of the applets was monitored and usage statistics were collected. We have received extremely positive feedback from students using the applet. Most students indicated that the applet helped them develop a better understanding of the subject matter and that it gave them the opportunity to experiment with various configurations of beams and support conditions without having to perform the many tedious calculations. From an instructional perspective, the influence line applet has made it possible to not only use “real world” problems in class, such as continuous beams with multiple spans, rather than oversimplified examples but to also consider a wider variety of problems than would otherwise not have been possible.

Summary and Conclusions

The influence line applet is a very valuable tool in teaching the basic concepts of influence lines analysis and in understanding the effect of moving loads on structures. The interactive nature of the applet allows students to easily create the beam model and visualize the results as changes are made to the model. Although it is relatively easy to draw influence lines for statically determinate beams, extensive computations are required to draw influence lines for statically indeterminate beams. Rather than go through the tedious exercise of obtaining quantitative influence lines for indeterminate structures, the usual approach taken in most introductory structural analysis courses is to draw qualitative influence lines using the Müller-Breslau approach. The influence line applet is a valuable complement to this since students can first draw qualitative influence lines and then use the applet to obtain quantitative influence lines

The influence line applet can also be used in bridge design courses usually taught at the graduate level. With the aid of this applet it is very easy to determine the placement of truck loads such as a standard AASHTO truck on a bridge and compute the maximum value of the response due to this truck load. Since the applet is self-contained and is available over the web, it is quite easy for instructors to integrate the use of the applet in their courses.

In summary, the influence line applet is a valuable tool that uses a novel approach for teaching a

difficult topic. It provides students with a means for checking their work, reinforces fundamental concepts learned in class, and enhances their learning experience by allowing them to experiment by building different types of beams and studying the effect of moving loads on these beams.

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Bibliography

- American Institute of Steel Construction (1993). *LRFD Manual of Steel Construction*, Chicago, Illinois.
- Barker, R.M., and Puckett, J. A. (1997). *Design of Highway Bridges*, John Wiley and Sons, Inc., New York.
- Hibbeler, R. C. (1999). *Structural Analysis*. Prentice Hall, Upper Saddle River, New Jersey.
- Kassamali, A. (1990). *Structural Analysis*, Second Edition. PWS Publishing.
- Kennedy, J. B., and Madugula, M. K.S. (1990). *Elastic Analysis of Structures, Classical and Matrix Methods*, Harper and Row Publishers, New York.
- Kinney, J. S. (1957). *Intermediate Structural Analysis*, Addison-Wesley, Reading, Massachusetts.
- Rojiani, K. B., Kim, Y.Y., and Kapania, R. K. (2000). "Web-Based Java Applets for Teaching Engineering Mechanics." Proceedings, ASEE Annual Conference, June, St Louis, MO. Session 2620.
- Rojiani, K. B. and Schottler, R. (2000). R. "Java Applets for Structural Analysis." Proceedings, ASEE Annual Conference, June, St. Louis, MO. Session 1315.
- Rossow, E. C. (1996). *Analysis and Behavior of Structures*, Prentice Hall, Upper Saddle River, New Jersey.

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