# VISUALIZATION TECHNIQUES FOR STRUCTURAL DESIGN EDUCATION

**Mohammed E. Haque, Ph.D., P.E.**

**Texas A&M University, Texas, USA**

## Abstract

The contemporary information technology (*IT*) allows us to develop learner-centered virtual design studios that can be reached to a large student population via the web. Considerable pedagogical advantages can be achieved by the integration of *IT* and visualization tools in teaching engineering technology. Structural analysis and design concept visualization, whether in reinforced concrete or steel structure is a subject that depends on geometric and physical perception, and every effort should be made by educators to enhance this ability. This makes it an interesting challenge in an exciting area, requiring creativity, imagination, as well as knowledge, and systematic thinking. Although the classroom environment in Engineering and Construction Science is highly structured by the instructor, teaching students to be critical thinkers is essential in the virtual classroom of the future. The textbooks available in structural design are mostly prepared for engineering students, and do an excellent job, but the associated rigorous theories make it an uninteresting academic hurdle for many below mediocre students. However, when the theories are exemplified in a virtual environment with multimedia, animation, interaction, virtual walk-through, and manipulated image visualization techniques, students' conceptual understanding are enhanced. This paper demonstrates various design concept visualization techniques including image visualization/animation, image manipulation, interactive flowchart based analysis and design animation, and walk-through virtual navigation. These visualization techniques can be valuable aids not only in teaching design principles in the class room but also an effective self directed tool for open learning via the web. All the techniques as discussed in this paper employ a generic programming architecture, which is discipline independent and can be adapted to any other similar domain, which will certainly promote and enhance students' understanding.

## Introduction

As technology rapidly changes, the importance of educating and training diverse populations of civil/construction engineering/science students becomes more critical. With the advances in information technology (*IT*) over the last decade, the traditional teaching format of having an individual lecture to an audience has been supplemented, and in some cases, replaced by the rapid development and implementation of new distance learning methods. Classroom use of *IT* for teaching science, engineering and technology has increased dramatically in recent years and has proved to be very effective in various situations[1-7]. Contemporary applications of *IT* allow us to develop learner-centered virtual design studios that can be reached to a large student population via the web. Enhancing World Wide Web developments, the new opportunities for interactivity and flexible access to various media format (text, sound, static illustrations, 2D and 3D dynamic illustrations, Virtual Reality worlds) challenge the traditional experience in shaping learning environments for web-based education[4]. The student-centered distance-learning archetype should include dynamic demonstration of theoretical engineering models allowing students to manipulate, experiment, and translate theories into real-world applications. Visualization is an important factor in modern education. Traditional lecture format teaching methods sometimes fall short of conveying the complex analysis and design principles that need to be mastered in reinforced concrete design course. One of the methods of reducing this short fall is to use simple animated virtual models, which demonstrate basic structural design concepts that can be used to enhance the students understanding. The interactive computer aided learning[1-3] allows students to proceed at their own pace, motivated by a curiosity about "what happens" interactivity and "the need to know" the design/ analysis principles.

This paper demonstrated various design concept visualization techniques for reinforced concrete design, and their developing means and methodologies. These visualization techniques can be valuable aids not only in teaching design principles in the class room but also an effective self directed tool for open learning via the Web.

**Visualization and Animation Techniques**

The visualization techniques that are discussed here are broadly classified under the following categories:
1. Image visualization/Animation
2. Digital Image Manipulation
3. Interactive flow-chart based analysis/design
4. Java-VRML based Design Animation
5. Walk-through Virtual Navigation

<u>*Image Visualization/Animation*</u>- The image visualization and animations are powerful tools for teaching design courses. If a student has a difficulty with a structural analysis and design problem, the animations of the structural response to loads explicitly show the foundations of the design mechanics by showing the connectivity between cause and effect. The author has created several GIF (Graphical Interchange Format) animations for beam flexure and shear. Figure 1 depicts a beam flexural failure animation creation using Adobe Image-Ready. It has animations of load increments, bending moment and beam deflection increments, tension crack growths and final collapse. In GIF animation, several

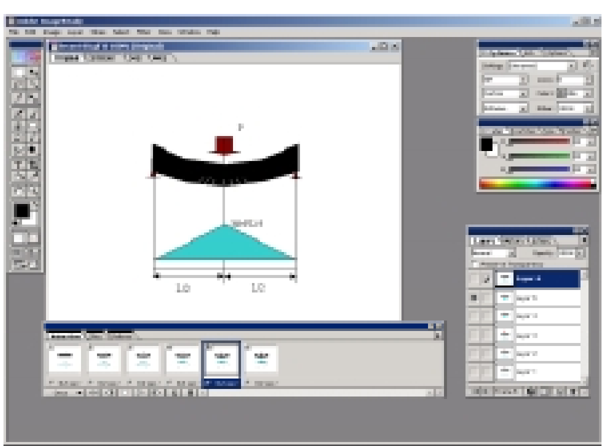

Figure 1: Beam flexural failure animation creation using Adobe Image-Ready

frames are displayed in a rapid succession, which creates the illusion of movement. GIF is the most important tool for bringing animation to the web. The GIF animation files are small, do not require any special plug-ins, and are easy to create.  There are many other programs available for GIF animation, such as GIFmation, GifBuilder, GIF-Construction, Adobe Photoshop-ImageReady, Macromedia Flash, and Freehand.  To open a Flash Player movie or animation in a browser, user must first open an HTML document, which in turn activates the Flash Player and runs the movie.

*Digital Image Manipulation* - Once the students see the real structural failures and try to understand the mechanics behind the failures with the help of manipulated images, their interest to learn the theories of structural designs grow many folds. The manipulated digital images are powerful tools for teaching design courses. If a student has a difficulty with a complex problem, these annotated versions of manipulated images explicitly show the foundations of the design mechanics by breaking up the problem into their natural components, and showing the connectivity between those components.  Before a topic is presented in its abstract form, students are shown a concrete representation of the problem. For example, when demonstrating the mode of reinforced concrete failure behavior, this will show appropriate digital manipulated images with power point subject presentation. For example, Figure 2 shows the arrow notation used by the model to explain the shear failure modes in a reinforced concrete column.

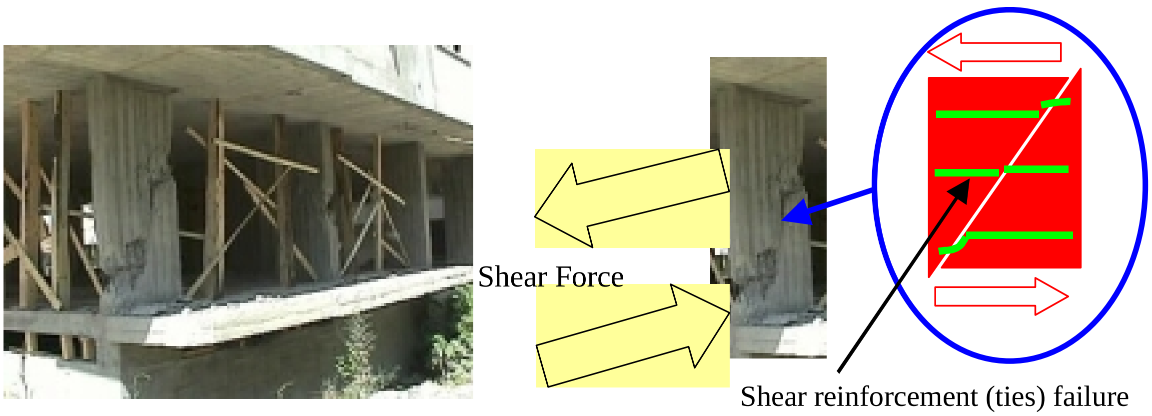


Figure 2.  Shear cracks in column.
(The Adana, Turkey Earthquake of June 27, 1998; Photograph Sources: EERI on Line Exclusive[8])

*Interactive flow-chart based analysis/design*

The structural analysis and design flow charts are easy to follow for students. This section presents a new approach to teach structural analysis and design using interactive flow charts drawn on Excel spreadsheets with 2D and 3D diagrams embedded or linked and other visualization models including VRML and walkthrough hyperlinked to the flowcharts.  Figure 3 shows a partial screen of an interactive flow chart for T-beam analysis. The use of the interactive flow charts may be useful in various ways:

- Ready to use steps for a student who likes to do calculations on spreadsheets.
- As the detailed step-by-step analysis/design procedures, equations, and design code requirements are shown within the flow charts, and equations are set within the spreadsheet, the flowcharts are easy to understand and very user friendly.

■ As a quick and accurate easy-to-follow reference for the engineers.

Since the entire flow chart is interactive, the content of the flow chart blocks will be depicted or erased based on the conditions, such as "if", "true/false", etc. For example, in a T-beam analysis, there are two cases to be considered: case 1 when the depth of the compression block is within the flanged portion of the beam (Neutral Axis, N.A. depth is less than the slab thinness), and case 2 is when the depth of the compression block is larger than the flange depth. In figure 3, "if" flow chart block found that it was case 2, which is a true T-beam analysis case. The flow chart was depicted in the case 2 direction, where as in case 1 (rectangular beam analysis) direction, the flow chart blocks were empty.

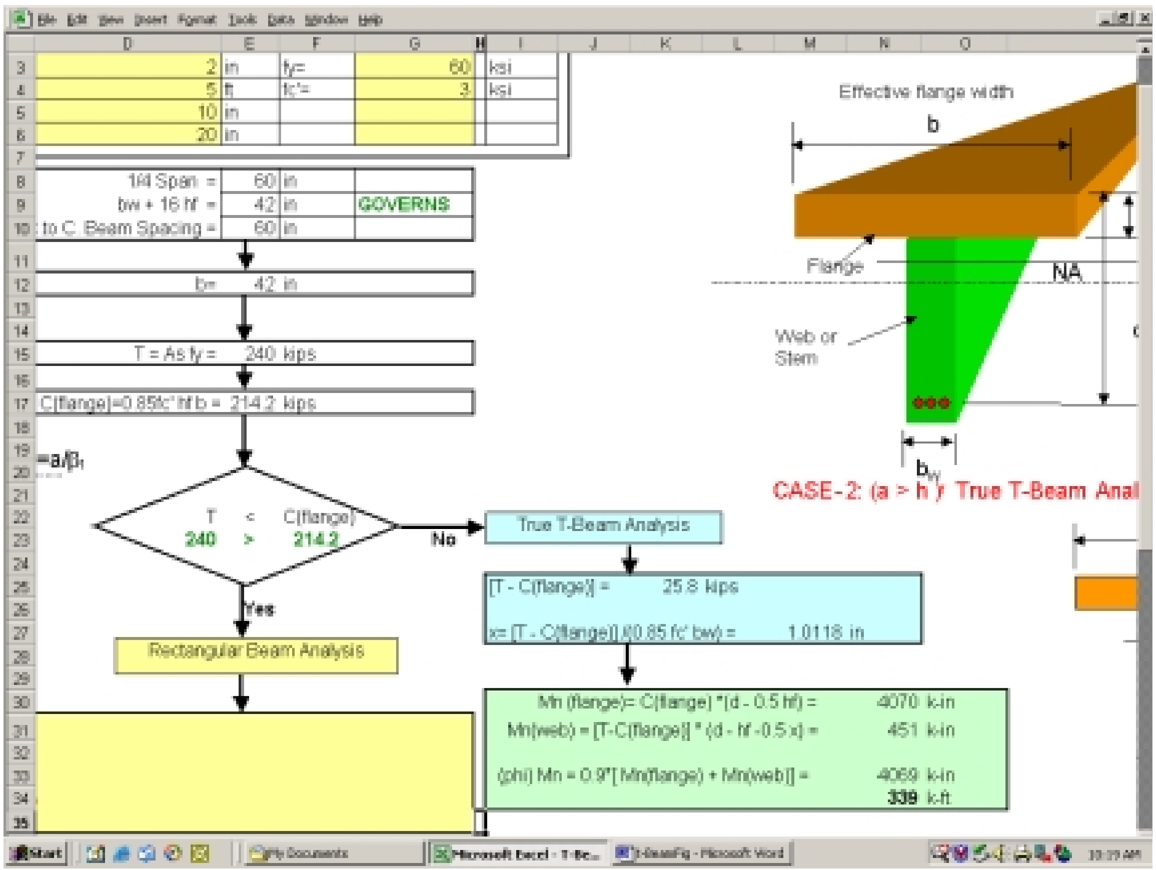


Figure 3. Partial view of an Excel spreadsheet showing T-beam analysis using interactive flow chart

<u>*Java-VRML based Interactive Design Animation*</u> - The dynamic virtual models can promote and support the professor led motivational lectures as well as self-directed experiential learning activities. Figure 4 shows Java model screens, where the user is allowed to define the load and beam geometry values[2]. Next, the user can interact with the beam by varying the structural load using up and down arrow keys. Once the designed critical moment values are exceeded, animation sound of concrete cracking with message box and calculated stresses are displayed. Results such as beam deflection, bending moment and shear force values are also shown on each user interaction with loads. As the load is increased moment, deflection and shear forces increase. The conceptual principle adopted here is to reinforce students understanding of the

behavior of concrete beams with the aid of simple structure such as simply supported beam with a point load on center of the beam. To deliver the interactive content (Figure 4) on the web, Java programming language was used because of its platform and operating system independence. The WebGAIN's Visual Cafe 4.0 software was used to develop the Java applet. The Visual Cafe is a visual Rapid Application Development (RAD) tool designed exclusively for Java programming language. It is a complete form-based development environment that provides a rich set of What-You-See-Is-What-You-Get (WYSIWYG) tools and components that enable the program developer to develop, debug, and deploy high-performance Web applets and stand-alone Java applications. For running this model on a PC, one needs Java plug-ins, which are freely available on many web sites.

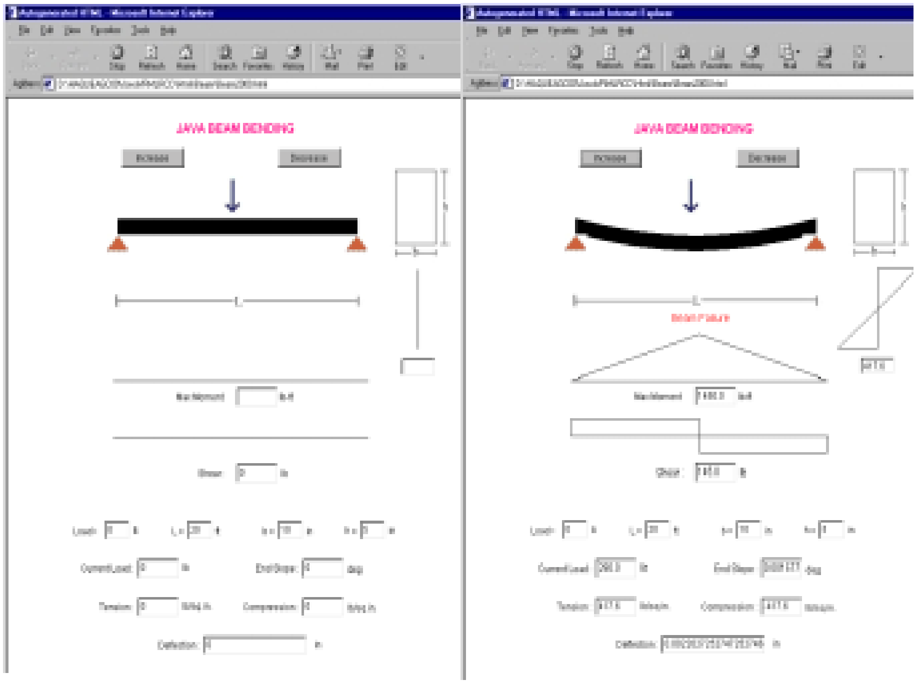


Figure 4. Java based Interactive Beam Analysis Animation

*Walk-through Virtual Navigation*- It is found that most of the current internet-based educational applications do not represent 3D objects even though 3D visualization is essential in teaching most engineering design principles. The author strongly believes that if 3D objects can be presented on the Web and be interactively changed/navigated, it will be beneficial for the students' conceptual understanding on the domain topics[1-3]. For example, the capabilities of VRML Model (Figure 5) include calculating number of reinforcement for simple structures such as a T-beam, generating the position of this reinforcement and plotting the 3-D navigational structure. Inputting beam dimensions and load information in a JavaScript based program, this generates the information in a VRML world file for view from any direction/angle and walk through the designed structure. It requires a web browser for interpreting standard HTML and JavaScript, such as Netscape or Internet Explorer, and a VRML browser such as Cosmo Player. In practice, VRML is a text-based language, where objects are defined as geometries in this modeling language. The Silicon Graphic's Cosmo Worlds 2.0 was used to create the VRML files. There are other software

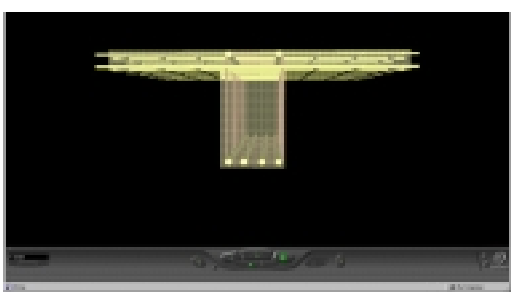

Figure 5. VRML model of a T-beam

available, such as **VRMLout** for AutoCAD, which is an ARX (AutoCAD Runtime Extension) application for AutoCAD Rel.13/14, AutoCAD 2000/i, 2002, Architectural Desktop and Mechanical Desktop. It allows exporting any 3D objects from AutoCAD to VRML format. VRMLOUT requires AutoCAD 2002, 2000/i (separate version for R13c4/R14), Architectural Desktop 3.3 or Mechanical Desktop R4/5/6 running on Windows NT/2000/XP or Windows 9x. The exported VRML files can be rendered by any Internet browser with appropriate VRML plug-in module (e.g. Cortona, Live3D, Cosmo, and others).

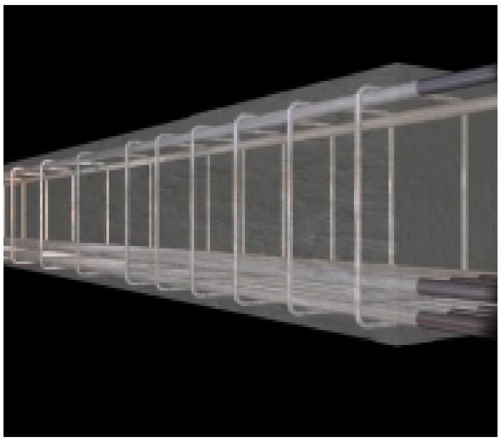

Figure 6: Walk-through within a transparent reinforced concrete beam

Nothing can be more convincing to a student than being walked-through a virtual model of a transparent concrete beam with reinforcement details (Figure 6). With a walk-through, things can be discovered, added or corrected before the actual construction begins. The 3D image and walkthrough animations was done using various functions of 3D-Max including photo-realistic lighting, camera matching, creating custom materials, volume lights, space warps, putting objects on paths, track view editor, skinning, etc. Animations involving just camera motion through a static scene or around a static object are adequate for many different applications. Using only camera motion, the viewer can see what it would be like to walk through a transparent concrete beam, which exists only as a computer model. This walkthrough is an excellent way to show the students the reinforcement details. Instead of 3D-Max, Maya can be used which is a very high quality 3D modeling, animation, and rendering software. It is used primarily to produce models and 3D graphics for movies, computer games, TV shows, and commercials. It is also used in industrial design applications to provide dynamic/animated visualizations. A person can create a model, animate it, and render it completely in Maya.

## Conclusions

Various visualization techniques as discussed in this paper can be valuable aids not only in teaching design principles in the class room but also an effective self directed tool for open learning via the Web. The Web based teaching and learning has potential advantages compared to traditional education since it is less expensive, easy-to-access, easy-to-update and platform independent. One of the true benefits of the proposed courseware with five concept visualization modules as discussed in this paper is its flexibility of usage in design education. The informal feedback from students has been positive as being a useful self-learning mechanism. The animation/visualization techniques provide virtual experiential learning when combined with interactive design animation and virtual design navigation. These activities are self-directed, experiential, and personalized for the autonomous self-directed distance learner. All the techniques as discussed in this paper employ a generic programming architecture, which is discipline independent and can be adapted to any other similar domain, which will certainly promote and enhance students' understanding.

## Bibliography


1. Haque, M.E. "Web-based Visualization Techniques for Structural Design Education" American Society for Engineering Education, 2001 ASEE Annual Conference Proceedings, Section 2793 Multimedia, Albuquerque, NM, (2001).
2. Haque M.E., Vamadevan A., Duraimurugar S., and Gandlur Y. Java and VRML based Interactive Reinforced Concrete Design Course Studio. American Society for Engineering Education, ASEE 2000 Annual Conference Proceeding, Section 1315 Use of Computer Technology to Enhance CE Education, St. Louis, MO, (2000).
3. Haque, M.E. "3-D Visualization and Animation Techniques in Structural Design Education," the International Conference on IT in Construction in Africa – Construction Information Technology, CIB W78 Conference Proceedings, pp. 2.1 – 2.9, Mpumalanga, South Africa, (2001).
4. Klett, F. "Designing a virtual learning space with 3D real-time presentation and advanced navigation" the 32nd ASEE/IEEE Frontiers in Education Conference Proceedings, session S2E, Boston, MA, (2002)
5. Jain K. and Noble, D. An interactive Web-based teaching tool for simplified 3D analysis of solar rhythms. Elsevier, Automation in Construction, pp. 181-194, 8(1998).
6. Haque, M.E. "Interactive animation and visualization in a virtual soil mechanics laboratory" the 31st ASEE/IEEE Frontiers in Education Conference Proceedings, session T1C, Reno, NV, (2001)
7. Kocijancic, S. and O'Sullivan, C. "Integrating virtual and true laboratory in science and technology education" the 32nd ASEE/IEEE Frontiers in Education Conference Proceedings, session T2E, Boston, MA, (2002)
8. EERI On Line Exclusive: http://www.eeri.org/earthquakes/Reconn/AdanaExclusive/AdanaExclIndex.html


**MOHAMMED E. HAQUE, Ph.D., P.E.**

Dr. Mohammed E. Haque is an Associate Professor of the Department of Construction Science at Texas A&M University at College Station, Texas. He has over fifteen years of professional experience in analysis, design, and investigation of building, bridges and tunnel structural projects of various city and state governments and private sectors. Dr. Haque is a registered Professional Engineer in the states of New York, Pennsylvania and Michigan, and members of ASEE, ASCE, and ACI. Dr. Haque received a BSCE from Bangladesh University of Engineering and Technology, a MSCE and a Ph.D. in Civil/Structural Engineering from New Jersey Institute of Technology, Newark, New Jersey. His research interests include fracture mechanics of engineering materials, composite materials and advanced construction materials, computer applications in structural analysis and design, artificial neural network applications, knowledge based expert system developments, application based software developments, and buildings/ infrastructure/ bridges/tunnels inspection and database management systems.