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INTERNET-BASED DISTRIBUTED COLLABORATIVE ENVIRONMENT FOR ENGINEERING EDUCATION AND DESIGN

A Dissertation

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Qiuli Sun
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P.O. Box 1346
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COLLABORATIVE ENVIRONMENT FOR

ENGINEERING EDUCATION AND DESIGN

A Dissertation APPROVED FOR THE SCHOOL
OF AEROSPACE AND MECHANICAL ENGINEERING

By

Kurt Gramoll, Ph.D.

Harold Stalford, Ph.D.

Kuang-Hua Chang, Ph.D.

Zahed Siddique, Ph.D.

David A. Sabatini, Ph.D.

Dedicated to

my son, Jerry Sun,

my wife, Shuo Yang,

and my mother, Yufu Tang.

This accomplishment would not have been possible without

the constant support and encouragement of my wife and mother.

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Abstract

The expanding use of the Internet has provided tremendous possibilities for engineering education as well as engineering design and analysis. With the use of the Internet, new approaches can be adopted to teach engineering concepts, and distributed collaborative engineering design and analysis become possible. This research investigates the use of the Internet for engineering education, design, and analysis through the presentation of a Virtual City environment.

The main focus of this research was to provide an infrastructure for engineering education, test the concept of distributed collaborative design and analysis, develop and implement the Virtual City environment, and assess the environment's effectiveness in the real world. A three-tier architecture was adopted in the development of the prototype, which contains an online database server, a Web server as well as multi-user servers, and client browsers. The environment is composed of five components, a 3D virtual world, multiple Internet-based multimedia modules, an online database, a collaborative geometric modeling module, and a collaborative analysis module. The environment was designed using multiple Internet-based technologies, such as Shockwave, Java, Java 3D, VRML, Perl, ASP, SQL, and a database. These various technologies together formed the basis of the environment and were programmed to communicate smoothly with each other.

The online database was designed to manage the changeable data related to the environment, because it is an efficient approach to save, delete, retrieve, and search data. The virtual world was used to implement 3D visualization and tie the multimedia modules together. Students are allowed to build segments of the 3D virtual world upon

completion of appropriate undergraduate courses in civil engineering. The end result is a complete virtual world that contains designs from all of their coursework and is viewable on the Internet. The environment is a content-rich educational system, which can be used to teach multiple engineering topics with the help of 3D visualization, animations, and simulations. Each multimedia module can be used to teach one specific engineering topic.

The concept of collaborative design and analysis using the Internet was investigated and implemented. The key elements of collaboration, such as sharing information, communication, and manipulation of design objects, are integrated into the environment. Geographically dispersed users can build the same geometric model simultaneously over the Internet and communicate with each other through a chat room. They can also conduct finite element analysis collaboratively on the same object over the Internet. They can mesh the same object, apply and edit the same boundary conditions and forces, obtain the same analysis results, and then discuss the results through the Internet.

Three assessments were conducted over a period of three semesters. Four modules were evaluated in the assessment: traffic engineering, structural analysis, collaborative geometric modeling, and collaborative engineering analysis modules. The results were analyzed statistically, which demonstrates that the environment is helpful in engineering education and design.

The research has led to the development of an Internet-based software environment for engineering education and design. It is the first Internet-based prototype integrating 2D simulations and 3D visualization in one environment. In addition, it is the first collaborative framework for engineering education. It is also the first Internet-based application that can be used to conduct 3D finite element analysis collaboratively with original considerations of implementation altogether. Nine multimedia modules were developed, and each contains multiple unique features. For example, the user can use the structural analysis module to define the truss and frame structures intuitively and conveniently by drawing individual members. The modules can be used to encourage learning about specific engineering topics. Multiple Internet-based technologies were seamlessly integrated to form the basis of the prototype. The customized 3D virtual worlds are generated using Perl, ASP, VRML, and the online database. Shockwave and Perl talk to each other to create new virtual objects. Shockwave and Java communicate smoothly to allow the user to design geometric models collaboratively. Standard stack data structures were simulated by the list data structures of Lingo to solve the management problem of the channels efficiently in Shockwave. Essential elements about distributed collaboration and Internet-based engineering education were discussed. The Virtual City is open to the public at www.vcity.ou.edu.

Chapter 1: Introduction

The expanding use of the Internet has provided tremendous possibilities for engineering education as well as engineering design and analysis. New approaches can be adopted to teach engineering concepts with the help of the Internet. Internet-based simulations, online collaborative learning, and virtual worlds are three applications available among the many possibilities. In addition to engineering education, the ubiquity of the Internet has made distributed collaborative engineering design and analysis possible. Geographically dispersed engineers will be able to complete design and analysis tasks jointly through the Internet. The research investigates the use of the Internet for engineering education, design, and analysis through the presentation of a Virtual City environment. The Virtual City environment is proposed because both industry and engineering education need prototype applications with efficient utilization of the Internet and computing power. The environment is open to the public at www.vcity.ou.edu.

1.1 Definition of the Need

1.1.1 The Need for Efficient Utilization of the Internet and Computing Power

The Internet is a matrix of individual networks that connects computers around the world. Computers with Internet access must have globally unique Internet Protocol (IP) addresses. IP addresses are hierarchical, which makes it easy to route information and access computers with specific IP addresses. Due to its omnipresence, the Internet can be used to distribute information easily to the public. In contrast, individual networks may run in local environments without IP configurations and be open only to specific users. Hence, this research systematically examines the use of the Internet for engineering education, design, and analysis.

Bandwidth and quality of service offered by the Internet are current major concerns along with connectivity. However, with the introduction of new networking technologies, such as wave division multiplexing, bandwidth concern will become less of a problem. The networking industry has already been able to reach a transmission rate of three terabits per second over a single fiber [1]. New Internet technologies, e.g. IP version 6, multicasting, and quality of service, are being developed [2, 3]. Many technical problems associated with the existing Internet will therefore vanish. A large number of new Internet-based applications will be needed to utilize the power of these new technologies efficiently. Internet-based engineering education and distributed collaborative engineering design and analysis are two paradigms among many possible applications.

Not only are Internet technologies improving, but processor speeds are also continuing to increase. It is reported that the maximum processor speed will be approximately 12 GHz by 2005 if Moore's law holds for three more 18-month cycles [3]. This is because numerous new technological innovations, such as advanced product manufacturing techniques and next-generation microprocessor architectures, are being adopted by the computer industry. In order to use the computing power efficiently, new applications will also need to be developed.

1.1.2 The Need of Industry

Industry needs these new applications to address a number of problems. One important industrial problem is that an individual engineer or a single company will not be able to complete an entire design task alone as engineering design becomes increasingly complex and international competition grows. To introduce a product into the market in a timely fashion, concurrent engineering must be used to coordinate product development that involves designers from different departments in the same company, as well as from different companies. Because approximately 80% of a product's life-cycle development cost is driven by decisions made in the first twenty percent of the program effort, concurrent engineering encourages early supplier involvement and even inclusion of outside partners [5]. Early key decision-making should be supported by experts from important suppliers and outside partners due to the complexity of the products and the reliance on special technologies. Besides concurrent engineering, collaborative engineering is another concept used in product development. It emphasizes team-based exchange of useful engineering information to create a shared understanding [6]. The creation of a shared understanding among team members is essential. Only after a shared understanding is achieved can the team members address common problems successfully. There are numerous immediate benefits of collaborative engineering, such as better communication among team members, more shared understanding, faster team decisions, and improved respect for cross-functional team mates. Long-term paybacks include shortened development cycles, lowered development costs, improved product innovation, and increased product quality. Industry has actually realized the importance of online smooth collaboration. For example, Bill Gates of Microsoft said in an email sent to developers and IT professionals that he envisioned an online world where constellations of Internet-based services could collaborate seamlessly [104].

The designers and experts are often geographically separate and it is almost impossible to move them all to the same working location. Traditionally, meetings, faxes, and phones are used to coordinate design work (Fig. 1.1). These methods can cause misunderstandings, delay of information transfer, and design conflicts, because complete product design information is not accessible to designers and experts when needed. Systems currently available on the market implement only some features of both concurrent and collaborative engineering by transmitting the modified digital model and its viewpoints between different computers. The modified digital model is then updated on each connected computer, which gives the users the impression that they are working on the same model [7]. It is therefore essential to design an Internet-based environment that can support the key concepts of both concurrent and collaborative engineering.

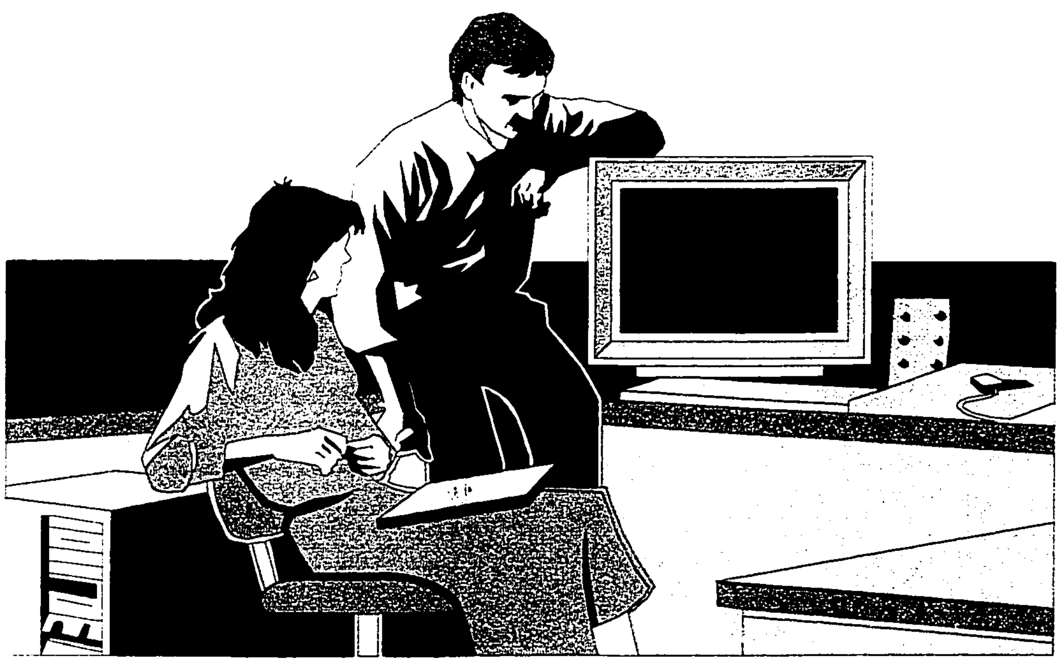


Fig. 1.1 Traditional Meeting on Design

1.1.3 The Need for Education and Training

Educational institutions also need these new applications to address their unique problems. As student populations increase, universities face the challenge of maintaining high standards and effective education [8]. This is particularly true in the resource-intensive engineering field. In industry, technological innovations are taking place every day. Engineers and technicians must always continue learning in order to master new technologies. Hence, efficient and inexpensive methods must be found to complement traditional education and training. One solution is to use the Internet with its advantages of low cost, convenience, and collaboration. Currently, an increasing number of people have realized the importance of Internet-based education. For example, on November 16, 1999, John Chambers of Cisco delivered a keynote address to a Comdex audience at Las Vegas. In his address, he described taking advantage of e-learning, calling it the "second wave" of the Internet [9]. Through e-learning, employees will have life-long learning opportunities, through which they will be able to learn whatever they want when they need it. However, Internet-based education is still in its infancy. One of the obstacles to Internet-based education is a lack of infrastructure and content-rich applications [9, 10].

1.2 Obstacles and Solutions

In order to reach the goal of concurrent and collaborative engineering, research is being conducted continuously; however numerous obstacles exist with current research. The first obstacle to achieving the goal is a lack of available homogeneous computer resources. Computer systems often vary among different companies, various departments in a single company, and even among different working groups in a single department. Difficulties in realizing distributed design over so many computer systems are obvious.

Research has focused on how to coordinate these computer systems into one distributed design environment.

The second barrier to reaching the goal is that it is difficult to implement 3D visualization of design objects over many computers at the same time. For this reason, current stand-alone 3D applications work only on local machines. There is no communication among them.

The third obstacle is network bandwidth. Small network bandwidth makes large data exchange slow and difficult, and frequent large data exchange is necessary in a distributed collaborative design environment. However, with the development of Internet technologies such as Virtual Reality Modeling Language (VRML), Java, Java 3D, IP version 6, and quality of service, it has become possible to develop a real distributed collaborative environment that can run on heterogeneous computer systems. This is because Internet technologies have been designed for distribution over multiple platforms. For example, by using VRML and Java 3D, it is possible to implement 3D visualization in a distributed design environment with multi-user capability. Bandwidth concern will become less of a problem as Internet bandwidth is continuing to grow. The delivery of high-definition video data over the Internet2 has already been successfully tested [2].

Institutions of higher education were one of the first to adopt the Internet as a tool for education because of its ease of use, inexpensive cost, and fast speed of access. Much research has been done in this area [36, 42]. However, most of the research has focused on individual courses. Few have provided prototypes from the point of engineering education where collaboration is important, and therefore most existing applications are separate entities. A solution to these problems is to use Internet technologies to design a environment with rich content for engineering education that supports 3D visualization, interactivity, design, and analysis.

1.3 Research Objectives

The Virtual City environment has been developed to utilize the increasing bandwidth and computing power efficiently by addressing both the educational and industrial problems. This Internet-based framework is a collaborative educational environment. It was designed to teach multiple engineering topics with the help of 3D visualization, animations, and simulations. An Internet-based 3D virtual world was implemented with a true 3D perspective that allows the users to avoid the high cost of actually building the design, which is impractical with many engineering projects such as large buildings and complex machines. Students are allowed to build segments of the 3D virtual world corresponding to appropriate undergraduate courses in civil engineering. The end result is a virtual world that includes designs from all of their coursework. The virtual world is viewable on the Internet. An online database was designed to manage the changeable data used in the Virtual City. Nine multimedia modules were developed for specific engineering topics. These modules are highly interactive, because they used the graphic representations as input and output. The students can learn the engineering topics by exploring the modules. The multimedia modules are connected together by the 3D virtual world. Generated 3D structures can be deposited in the virtual world. Three assessments were conducted and analyzed to determine the effectiveness of the Virtual City environment.

The Virtual City environment can also be utilized as a test bed to conduct engineering design and analysis collaboratively over the Internet. Geographically dispersed users can build the same geometric model and communicate with each other simultaneously. Likewise, they can conduct finite element analysis collaboratively on the same object over the Internet. They can mesh the same design object, apply the same boundary conditions and forces, obtain the same analysis results, and discuss the results through a chat room. With the help of the collaborative environment, the amount of travel imposed on engineers, when they are located in different working sites, can be reduced. The flexibility of selecting engineers for design projects can therefore be increased.

In summary, the objectives of this research are as follows:

- To provide a content-rich infrastructure for engineering education
- To test the concept of distributed collaborative design and analysis
- To develop the Virtual City framework
- To assess its effectiveness in the real world

1.4 Contributions

This research has led to the development of an Internet-based Virtual City for engineering education, design, and analysis. It is the first Internet-based prototype integrating 2D simulations and 3D visualization in one environment. In addition, it is the first collaborative framework for engineering education. It is also the first Internet-based application that can be used to conduct 3D finite element analysis collaboratively with original considerations of implementation. Nine multimedia modules with unique features have been developed. They can be used to encourage learning about specific engineering topics. Generic modules, such as the structural analysis module and piping network modules, were designed to encourage creativity by minimizing restriction on the user's input. Multiple Internet-based technologies have been seamlessly integrated together to form the basis of the prototype. They were programmed to communicate smoothly with each other. The customized 3D virtual worlds are managed efficiently by the online database. A few unique programming techniques were also employed, for example, using the list data structure to simulate the function of the stack data structure. The importance of essential elements of distributed collaboration was discussed, and the key elements, such as information sharing and manipulation of design objects, were implemented in the environment. Finally, three assessments were conducted to evaluate the effectiveness of the Virtual City. Statistical data show that the Virtual City was helpful in engineering education and design, as discussed further in Chapter 8.

1.5 Potential Applications of the Virtual City

1.5.1 Potential Applications in Engineering Education

Due to the increasing Internet bandwidth and computing power, the idea of the Virtual City can be extended to design virtual products for the purpose of engineering education in the future. To obtain a mechanical engineering degree, the student usually needs to take numerous courses, such as statics, dynamics, and mechanics of materials, and machine design. Through careful organization, the student could integrate the knowledge from respective courses to design multiple meaningful parts that could be assembled together to form a virtual product. After the virtual product is designed, a virtual manufacturing module could be used to test the manufacturability of product parts. In detail, a virtual prototyping module could be used to build a complete prototype assembly with geometric models of individual parts. This module could check feasibility of assembly operations and perform static and dynamic simulations. Finally, a virtual factory module could be used to simulate the complete production procedure of that product. If something were to go wrong with the product, the user could redesign the products.

The main purpose in designing a virtual product is that the user can learn engineering topics by building individual virtual parts, testing manufacturability, and making the products in a virtual factory. As the whole procedure would be modeled after the methods industry uses to design real products, practicing engineers and students could learn valuable knowledge in this virtual environment. Although the whole system as envisioned seems particularly complicated, it should be less sophisticated than its industry-level counterparts. It could be highly efficient, because this Internet-based system could reach tremendous numbers of practicing engineers and students. Finally this model could be the basis of a virtual university for engineering education.

1.5.2 Potential Applications in Industry

In addition to a virtual university, the idea of the Virtual City also has potential applications in industry, especially in engineering. Because the Virtual City is a 3D world with a true perspective, it can be used for city planning. City designers in different locations can work collaboratively with the same view of the 3D city model.

Traditionally, design engineers and manufacturing engineers usually have difficulty in communicating, because current CAD/CAE/CAM products are individual programs, even though they are used extensively. Because design engineers and manufacturing engineers usually work in different places, they cannot easily show each other their 3D models and drawings. It is common for design engineers to go to factories to work with manufacturing engineers. However, the need to do so is expensive and imposes large amount of travel on engineers. It is even more expensive if sales people and outside experts are also involved in the product development. However, if the CAD/CAE/CAM products implements the idea of the Virtual City, it is possible to reduce the amount of travel imposed on people involved in the product design as well as to shorten development cycles. This is because the idea of the Virtual City is to allow geographically dispersed individuals to collaborate over the Internet.

There are two ways to provide traditional CAD/CAE/CAM products with distributed collaborative features. One way is rewrite the internal code of these products. Another way is to design an engine that sits between the internal code of CAD/CAE/CAM programs and their interface in order to transmit data. The latter way is a more reasonable solution to add distributed collaborative capabilities to existing CAD/CAE/CAM products, because rewriting the internal code is expensive and time-consuming. No matter which method is chosen, mainstream CAD/CAE/CAM products will implement the idea of the Virtual City to provide distributed collaborative capabilities in the future.

Chapter 2: Literature Review

A large number of papers on the distributed collaborative design and Internet-based education have been published. Numerous commercial products are also available on the market. The following is a discussion of the previous works conducted on distributed collaborative design and Internet-based education.

2.1 Distributed Collaborative Design

Research on distributed collaborative design falls into two categories. The first one attempts to offer theoretical models such as distributed object-based modeling and evaluation framework. As theoretical models are based on numerous assumptions, it is usually difficult to implement them. The second category of research tries to implement the idea of distributed collaboration in a practical way, such as web-enabled feature-based modeling, Cybercut, and OneSpace.

2.1.1 Distributed Object-based Modeling and Evaluation Framework

Senin, Pahng, and Wallace, et al. proposed a distributed object-based modeling and evaluation (DOME) framework for product design [11, 12, 13, 14, 15]. The basic goals of DOME are intended to link distributed design modules, aid designers in evaluating the system performance with different design alternatives, seek optimal solutions, and make design decisions. The key assumption of DOME is that product design problems can be decomposed into sub-problems. The sub-problems are modeled as modules containing their own sub-problems or internal design details. Each module has an interface that provides and obtains services from other modules. The product design can be realized by assembling the modules and by coordinating the services among the modules. As the design problem is subdivided into several modules, these modules can be designed in a distributed environment. They are able to exchange design information using a standard network communication protocol. In order to find the optimal solutions for the design problem, optimization methods such as genetic algorithms are used to help the designer make better decisions when design alternatives are possible.

The advantages of DOME are knowledge encapsulation of the module, distributed activities and design resources, trade-off analysis, and decision support. Because each module uses an interface to exchange information with other modules, expert knowledge and know-how are encapsulated in the module. This protects the intellectual property of the owner of the module. The product design problem is decomposed into sub-problems, which makes the distributed activities possible. The optimization method is integrated into DOME, which provides trade-off analysis and decision support.

Although DOME is reported to have numerous advantages as mentioned above, disadvantages do exist in DOME. The first disadvantage is that extensive effort is necessary to decompose the product problem. In order to exchange services, each module must have a standard interface. This is not easy because engineers in different companies separately design each individual module. The second disadvantage is that difficulty exists in dealing with circular dependencies of modules. The third disadvantage is that DOME assumes the modules are generated in a heterogeneous computer environment using specialized software tools. This creates problems with the smooth flow of information among modules.

2.1.2 Discourse Model for Collaborative Design

Case and Lu proposed a discourse model used in software environments that provides automation support for collaborative engineering design [16]. Their model treats interactions between designers as a process of discourse. In this model, design commitments are considered as options, subject to review and revision by other designers. The model includes both structural and process specifications. A blackboard-based workspace of the structural specifications integrates frames, constraints, semantic networks, and libraries of sharable design objects, software agent modules, an electronic mail system, and a virtual workspace language based in part on the Knowledge Query Manipulation Language. Components of the process include specifications for identifying agent interest sets, applying state transformations to the design model, switching design contexts, finding conflicts between designers, and keeping track of resolved conflicts.

The discourse model is capable of managing a large complex design project requiring the collaborative efforts of a number of individuals. It also has the capability to detect unexpected conflict areas automatically among designers. Finally, it allows all interested designers have an opportunity to participate in the resolution of conflicts via conflict detection, rationalization, and resolution protocol. However, agents could not be sent into the working place of other users to act as design advisors and critics in real-time [16].

2.1.3 Web-enabled Feature-based Modeling in a Distributed Environment

Lee, Kim, and Han proposed a prototype to implement web-enabled feature-based modeling in a distributed environment [17]. The prototype was implemented in a server/client architecture, in which a feature-based solid modeling kernel worked as a server to perform most of the modeling, and a client worked as an interface to conduct graphical rendering and navigation and issue modeling requests. Multiple clients can connect the server at the same time. The server was implemented in C++, and the client was developed using Java and Java 3D. Common Object Request Broker Architecture (COBRA) was chosen as a communication protocol between the server and the client. No synchronous collaboration was implemented.

2.1.4 Process-centric Distributed Collaborative Design

In addition to web-enabled feature-based modeling, Kim, Lee, and Han proposed a prototype called Process-centric Engineering Design WorkSpace (PEDWorks) for distributed collaborative design [18]. PEDWorks deals with the collaboration of multidisciplinary design teams who are geographically dispersed. PEDWorks uses server/client architecture, which contains server-side applications such as a process controller, a design board, a communication server, and a CAD server, as well as client-side applications. Process flow graphs are used to represent complicated design problems. Design teams share design processes and critical design information. The processor controller monitors design conflicts and dependency. If a design conflict occurs, the process controller notifies the related designers. In PEDWorks, a collaborative conference can be requested to discuss the design problem synchronously. The participants of the collaborative conference communicate by text, audio, or video. They can load the same geometric model into their client computer from the database. However, no real-time manipulation of the same geometric model is supported. The client-side applications only talk with the server, and no peer communication is implemented.

2.1.5 Cybercut - A Web-based Design to Fabrication Tool

Cybercut is an Internet-accessible and computerized machining service system developed at the University of California at Berkeley [19, 20, 21, 22]. Currently, it provides Internet-based services such as design-for-manufacturing CAD, Computer Aided Process Planning (CAPP), and access to an open architecture machine tool for fabrication of mechanical parts. The client's computer is responsible for distributed geometric modeling and CAPP. The design and process information are transferred into a machine tool for fabrication. Three levels of agents - design agent, planning agent, and fabrication agent - are utilized to exchange information between design, planning, and fabrication.

Cybercut provides a 'parts-on-demand' service for mechanical parts, and allows rapid fabrication technology to be accessible by anyone with a web browser and an Internet connection. However, in order to manufacture parts designed by the user on a milling machine, a feature-based, constrained destructive solid geometry design environment is adopted. The user cannot build up the part from "nothingness", and the user must start a prismatic stock to remove certain shapes of material, referred to as "features". This is a practical way to solve fabrication problems at the beginning of design, but it restricts the design freedom of the user.

2.1.6 Agent-based Collaborative Design

An agent is a special autonomous software entity that is able to reason and thus achieve a specific goal. Agents can interact with each another, exchange data, and keep track of information. The agent technology can aid distributed engineering design. Toshiki Mori and Mark Cutkosky proposed an agent-based prototype implementation in the design of a portable CD player [23]. The agent interface was written in Java, which makes it possible for geographically dispersed design teams to communicate over the Internet.

The basic procedure of an agent-based collaborative design is as following. First, designer A creates part 1 of an assembly and publishes part 1. Designer B creates part 2 of the assembly and publishes part 2. Second, the design agent detects geometric interferences between part 1 and part 2, and sends warnings to the specific designers. Third, designer A modifies part 1 in an effort to eliminate the interferences and publishes the modified part 1. Fourth, the design agent finds no inference between modified part 1 and part 2. Fifth, designer B decides to change part 2 and then publishes the changed part 2. Finally, the design agent suggests that designer A reject modified part 1 and accept the original part 1.

One advantage of the agent-based collaborative design is that agents can track and respond to changes in the state of the design. A designer however has to publish a new design model in order for agents to trigger actions. In this case, it is difficult to achieve real-time collaboration for agent-based design.

2.1.7 Product Development Management System

To share CAD information seamlessly across an enterprise, major CAD suppliers have introduced a software system called product development management [24, 25, 26]. This software system extends CAD data not only to non-design departments of companies such as analysis, tooling development, manufacturing, testing, quality control, sales, and marketing, but also to suppliers and partners of these companies. The goal is to shorten product development cycles and streamline product design. The major product development management systems include Windchill from Parametric Technology Corporation, MetaVPDM from SDRC, ENOVIAvpm from IBM and Dassault Systems, ProductVision from Unigraphics Solutions, and OneSpace from CoCreate. Airbus, Sony, and Lockheed-Martin are among the early adopters [27, 28].

The product development management system centers on managing CAD information in a systematic way and sharing CAD information among design departments, non-design departments, and partners. Most of such existing systems are web-centric [29]. For example, Windchill's end-users in engineering, manufacturing, and other departments begin by going to the company's product information home page. Via hyperlinks, search engines, and applets, the end-users can navigate to work areas and product information. In this way, the end-users can always obtain the most current product information. Windchill uses a three-tier architecture - an Oracle 8 database as the foundation, Java object servers as middleware, and a browser on top.

The product development management system partially implements the idea of distributed collaborative design since synchronous collaborative geometric modeling and engineering analysis are not the focus of the system. The management system usually centers on asynchronous collaboration. For example, Windchill offers capabilities such as publishing product information, viewing product information, and collaboration notification. In particular, to view product information, a viewer can be used to display 3D models or 2D drawings for investigation, manipulation, and markup. The publishing and notification capabilities guarantee communication and notification of critical factors in product development, which allows product development teams to make better design decisions quickly and bring the products to the market faster.

2.1.8 Internet-based Engineering Service

With the growth of the Internet, an increasing number of manufacturing companies publish their product information on the Internet. In order to help the customers such as designers and other manufacturers obtaining desirable product information, Internet-based companies are established to provide sophisticated online search services that are able to find product components based on the customers' specifications [30]. Other efforts are made to link individual web pages to form a knowledge database, which provides search tools to find the solutions for a specific problem [31].

Another good example of Internet-based engineering services is offered by Inpart [32]. Inpart's DesignSuite consists of a library of 3D models of standard mechanical components for well-known suppliers, which is accessible for a fee via the Web. This is particularly beneficial to product design because mechanical products compose of numerous standard parts and components. Instead of creating the 3D models of the standard parts and components by themselves, the users can directly use the 3D models from Inpart, which can reduce designers' geometric construction work tremendously. To generate creative ideas and reduce product design time, companies such as Seagate are starting to use the Internet and teleconferencing to link different located design centers to form a virtual design center [33]. In this case, it is not necessary to move intellectual resources to one location and the cost of design is reduced consequently.

2.1.9 Distributed Editing Program and Collaborative Environment

Many Internet-based games are popular because of their multi-user capability. Game technologies can also be used in developing distributed collaborative environment.

One example is a distributed editor called SimulEdit created at CIT, which allows people in different locations to edit the same document using the Internet [34]. This editor supports peer-to-peer communication using Java on the Internet. Changes made by one person are immediately visible to everybody. Another example is Sieve, which is a prototype Java-based collaborative environment for constructing visualization interactively [35]. In this environment, multiple users can simultaneously construct and manipulate a data-flow network in real-time. The environment supports flexible collaboration by providing real-time information about participants' actions and locations in the workspace. Since Sieve was created using Java, it can run in the user's browser.

2.1.10 Asynchronous Commercial Collaborative Applications

Currently, numerous asynchronous collaboration applications, also known as groupware or teamware, are available on the market. HotOffice, Lotus Domino/Notes, Agillion, and Microsoft Exchange 2000 server are the most common ones [68, 69, 70]. Although different applications may have different features, they usually use client/sever architectures and offer a private Web site on which the authorized users can share files, schedule meetings, and post messages on an internal level. One of the advantages of these collaborative applications is that they alleviate the heavy use of e-mail as a communication method. Other advantage is that they can let people collaborate even if they are not available at the same time. AutoCAD 2000i is another recent product that can publish product information on the Internet using images in DWF or JPEG format [71]. However, as the name implies, asynchronous tools are not real-time collaboration, and in the case of AutoCAD 2000i, the objects are not actually built and edited on the web.

2.1.11 Synchronous Commercial Collaborative Applications

The purpose of synchronous collaborative applications is to let the users remain at their current locations and share information with each other. Not only are documents shared but also applications. Lotus SameTime is an example of a general-purpose real-time collaborative application that offers text chat, whiteboard, and application sharing [68]. Alibre Design explores the possibilities of using the Web as a collaborative tool in the product design field [72]. The heart of Alibre Design is a 3D parametric feature-based solid modeler, which can execute individually or execute and connect a design server and a repository server. A popular three-tier architecture is used to develop the whole system of Alibre Design. Both synchronous and asynchronous collaboration features are integrated in the system. The user can use local processor power to design parts and save them on local machine, and team members can collaborate in real time if needed. Another feature of Alibre Design is that it uses Application Service Provider model to conduct business, which is on subscription basis.

OneSpace from CoCreate is another example that uses the Internet to provide collaborative services to the product design [101]. The OneSpace collaboration system consists of a server and multiple clients. The collaboration server has a solid modeling kernel to hold the 3D geometric product models and takes care of communication between clients. The clients can trigger an upload of data into the OneSpace server for real-time viewing, inspection, conferencing, markup, and collaborative editing of the 3D model. The clients were designed using Java and benefited from Direct Model, a high-performance graphics framework from Hewlett-Packard. One promising feature of OneSpace is that it records the collaboration notes such as discussion, decisions, reasons for making changes, and ideas to investigate further along with the geometric models. The collaborative notes are particularly valuable because they capture the knowledge associated with the design. They may be reviewed later by the same designers or other engineers.

Synchronous collaboration is particularly useful when a critical design decision needs to be made by several geographically dispersed engineers. Because it allows engineers to discuss, review, and inspect the same design object simultaneously, design decision can be made quickly with the support of experts in different areas. One purpose of this research is therefore to investigate the concept of real-time collaborative geometric modeling and engineering analysis.

2.1.12 Collaborative Examples in the Engineering Media Lab

To help with collaborative learning, a multi-user Painting and Drawing Board was developed in engineering media lab using Director Multi-user [73]. The basic idea of the board is to use Director Multi-user Server, which routes data between multiple drawing boards. The main feature of the drawing board is that when a couple of users use the board in different locations, they can see each other's drawing. For example, when one user draws a box on the board, every other user sees the box immediately on their board, no matter where they are. Another feature is that the users can chat with each other while using the board. The drawing board is useful when several people discuss an engineering topic that needs a drawing to help understand the topic.

To assist students in solving statics problems jointly, a Truss Solver was developed using multi-user technology [73]. With the Truss Solver, geographically dispersed users can work and discuss on the same truss problem. The steps of solving the truss problem and its results are visible to every user, which implements the concept of collaborative learning and teamwork among students through the use of Internet.

In addition to helping with collaboration among students, the multi-user technology can also be used in industry. The Factory Layout Planner is an example that allows geographically dispersed engineers to work together on the same project through the Internet [73]. Along with multi-user capability, the planner employs VRML to demonstrate the 3D layout of the factory. The dispersed users not only share the 2D layout, but also the 3D layout using VRML through the Internet. This is particularly efficient when numerous users are working on the same layout and a lot of discussion happens. Similar to the drawing board, the Factory Layout Planner offers a chat room for the users to discuss the layout. The planner partially implements the idea of distributed collaborative design. This is because the planner does not allow the users to design new geometric objects and the users can only choose built-in geometric objects of the planner.

2.1.13 Summary of the Survey for Distributed Collaborative Design

From the above literature review, it is known that although work has been done in this field existing environments are still in their infancy. Current collaborative environments usually use the classical server/client architecture and have a powerful geometric modeling kernel sitting on the server. The functions of clients are quite limited and used mainly for displaying the models. This architecture therefore imposes high traffic between the server and clients. Although analysis is as importance as design, no research has been done on distributed collaborative engineering analysis.

This research proposed and implemented a different strategy, which can significantly reduce the network traffic between the server and the clients. Although the server/client architecture is still used, the task of geometric modeling is moved from the server to the clients. The server only takes care of the communication. The clients have the full capabilities to generate geometric models. Only a small amount of data is transmitted over the Internet in each operation. This is because the transmitted data is not the resultant geometric model, but related multiple commands. This research also developed the first collaborative environment for 3D finite element analysis over the Internet. The analysis environment takes the output of the design environment as its input. Both work smoothly together. Another important feature of the prototype is that it can export the geometric models into the 3D virtual world. The virtual world can therefore be built dynamically.

2.2 Internet-based Education

In addition to conducting the design of real products over the Internet, engineering education can also use the ubiquitous nature of the Internet. To answer how the Internet will affect the traditional higher education, a study sponsored by the California Education Round Table was performed [36]. Based on this study, it is believed that the Internet and the World Wide Web will play multiple important roles in the higher education. These roles include improving learning and teaching, improving the creation of instruction and learning materials, creating educational communities, competing with new educational providers, and adding policy and planning issues of the higher education. Because of these potential advantages, universities are not the only leading forces in the development of the Internet infrastructure technologies, but also are one of the first to adopt these technologies for educational purposes. Soon after the creation of the Web, universities started to employ it as a teaching tool to educate students and provide training services to the public. The industry also utilizes the power of the Internet to deliver training services. Learning companies, such as DigitalThink and Mentergy, offers e-learning solutions to clients, including custom courseware development, step-by-step consulting, and development and delivery tools [102, 103]. Learning companies have moved beyond universities in the sense of their offered services. A large number of papers have been published to address the issues of Internet-based education. Numerous ways have been used by universities or learning companies to provide Internet-based education and training, such as general course administration, information delivery, virtual laboratories, Internet-based simulations, online courses, and virtual universities.

2.2.1 General Course Administration

Currently, the web is utilized as a general course administration tool by almost every university. It has been used as an electronic way to distribute the course information such as syllabi, information on lecturers and teaching assistants, course description, reading lists, homework, and homework solutions. Many colleges, such as the College of Engineering at the University of Oklahoma, provide course-page templates for faculty use [37]. The templates provide an easy way for those professors who are not familiar with HTML to create course pages. The Virtual Classroom Interface (VCI) of the University of Illinois at Urbana-Champaign is another example, which provides templates to simplify the creation and administration of course web pages [38]. Its main objective is to automate the production process of course web pages and to reduce the effort of faculty members. At Case Western Reserve University, students are able to register for courses using the web to directly access Case's mainframe student information system [39].

2.2.2 Information Delivery

The web is an efficient way to deliver a large amount of information, such as online textbooks and other course materials. These web-based textbooks are similar to traditional textbooks. In addition to texts, the online textbooks usually also offer audio clips, video clips, simulations, and relevant links. Another advantage is that keyword searches are provided in these electronic books. The multimedia textbooks offered by the virtual hospital of the University of Iowa is a good example [40]. A hyper textbook written by Kenneth R. Koehler offers an overview of physics for students of biology and chemistry [41]. The first edition of this hyper textbook has already been translated into Japanese. A web-based database of course materials in computer architecture is being developed at North Carolina State University [42]. At the University of Oklahoma, manuals covering the use of Oracle databases are placed on the Web so that the students taking the database course can access them.

2.2.3 Virtual Laboratories

Virtual laboratories can be set up over the Web to resolve the problem of accessing expensive or dangerous experimental apparatuses such as laser devices, robots, and CNC (Computer Numerical Control) machines. Jack and Karlesky at Grand Valley State University developed a virtual manufacturing laboratory, which allows students to access robots, CNC machines, DAQ (Data Acquisition) cards, and other equipment using the web [43]. The students use the virtual reality devices to explore the equipment. They then simulate the program on a virtual robot. After they believe the program is functional, they can upload the program to the real robot and use a video link to monitor the robot. Pniower and Ruane, et al. at Boston University also designed web-based experiments to allow both local and remote users to conduct laboratory explorations using physical experimental apparatuses over the web [44]. In these experiments, users are able to transfer the data to the apparatuses, control the apparatuses, and observe the progress of the experiments employing a live video link.

2.2.4 Internet-based Simulations

Although it is generally agreed that the use of simulations in engineering education is beneficial to students, simulations are not widely used due to the relatively small target user groups, the cost of development, and distribution problems. With the introduction of the Internet technologies, these problems can be minimized.

An example of Internet-based simulations is "Mallard" which was developed by Mike Swafford and Donna Brown at the University of Illinois at Urbana-Champaign [45]. The Mallard environment uses several Java applets to teach freshmen electrical and computer engineering courses at the University of Illinois at Urbana-Champaign. Within the environment, students can do homework, and obtain immediate feedback about their solutions. Students can also conduct the design of assembly code. Two interactive Web-based applications called Virtual FlyLab and Virtual Earthquake were developed for learning science [46]. An innovative use of Internet technology for education is to employ VRML to teach design over the Internet. Ranga and Gramoll successfully implemented two Internet-based design examples with the help of Practical Extraction and Reporting Language (PERL) [47]. Another creative example is to use Java and VRML in teaching machine kinematics [48]. Traditionally, machine kinematics was taught using drafting tools. With the introduction of computer graphics and the Internet, it becomes more efficient to use these technologies to demonstrate concepts of machine kinematics visually in 3D models. Multiverse is a paradigm providing a standard interface for various Internet-based simulations [49, 50, 51] that facilitate the use of Internet-based simulation in education and training by employing Java and Web technologies.

2.2.5 Online Courses

As the web provides unprecedented flexibility and multimedia capabilities to deliver course materials, online courses are available for both on-campus and off-campus students [52, 53]. At the University of Oklahoma the basic statics class was taught using laptop computers, CD-ROMs, and the web [54]. The statics CD-ROM was used for main course content, which was supplemented with web-based material such as homework, examples, quizzes, solutions, and lectures. The lectures were videotaped, compressed into a streaming video format, and placed on the server. After the lecture was presented, students were able to access the video within one day. Using a wireless network card, the students were able to view the lectures on the web. This allowed them to attend class virtually anywhere on campus and provided the flexibility of learning on their own schedule. At the University of Tennessee, the graduate level finite element course was offered as a live, video-streamed lecture course over the web [55, 56]. Distance and off-campus local students as well as on-campus students were able to access the course materials. They were connected via a chat room and emails. Lam and Gramoll [57], and Chambers [58] presented their experiences of using video streaming technology to produce online courses. To minimize course delivery difficulty for distance education, the Georgia Institute of Technology recently utilized the Internet as a new delivery way to present online courses to remote students [59]. Compared to videotapes that were employed previously, the online courses allowed rapid distribution and were free from the problems generated by different video standards through the world. WebCT is a commercial tool that is widely used and provides a systematic framework to produce online courses [60].

Besides online courses for students, the Internet can also be used to provide the online review for general users. The Fundamental of Engineering Review project at the University of Oklahoma is another new paradigm that uses the web as a way to deliver an online review [61]. The purpose of the project was to provide a flexible, easily accessible, cost-effective, and interactive review package with the integration of multimedia technologies such as graphics, animations, audio, video, and simulations. In this online review, not only are basic topics reviewed but also there are the online exams with problems. These problems are randomly generated so that the problems are different each time the user takes the online exam.

To investigate the effectiveness of the online courses, research has also been conducted. David R. Wallace and Philip Mutton compared the effectiveness of web-based lecture and classroom-based lecture [62]. Their results showed that students who used the web-based lectures performed better than students who took the classroom-base lectures. Although the experiment was only on one topic, it rejected the hypothesis that the two groups should perform equally. In another experiment that was also conducted by David R. Wallace, the performance of two groups of students was investigated [63]. The first group prepared for class using web-base materials and then received a traditional class-based lecture that reviewed the topics in the class. The second group prepared for class using the same web-based materials and then worked with the lecturer, applying only a small portion of the subject in illustrative examples. After this, the students of these two groups completed an assignment. The average grade performance of the first group was 10.8% higher than that of the second group. The experimental finding suggests that traditional classroom time might be used for higher value-added activities such as mentoring and experiential activities if well-organized course materials are primarily delivered using the Web. At the University of Missouri-Rolla, the effectiveness of an online graduate engineering management course was investigated [64]. The results showed that nearly 58% students believed that taking online course was a more or significantly more effective learning experience. Although little documentation of the effectiveness of web-based courses is available and more research is needed to identify why web-based courses help learning, it does show that the web needs to be taken seriously as a effective tool to help students learn.

2.2.6 Virtual Universities

To expand the use of the online courses, virtual universities were established to offer educational services. Virtual Online University Services International, Inc. (VOUSI), a Virtual Corporation operating as a Corporate University, offers professional development and interactive education [65]. Athena University is a non-profit virtual university administered by VOUSI and offers undergraduate and graduate programs in a fully online and interactive environment. Magellan University is another virtual university that offers online courses in liberal arts and business [66]. The Virtual University of Michigan State University refers to courses offered through the Internet and other technologically enhanced media [67].

2.2.7 Summary of the Survey for Internet-based Education

Although the educational activities over the Internet are diverse, no existing educational environment can meet the requirements of 3D visualization, collaborative learning, and the encouragement of creativity and teamwork. These requirements are essential in education, especially in engineering education. A large number of simulations were designed, but they were only for individual courses. No content-rich prototype was developed from the viewpoint of engineering education.

The proposed research includes the development and implementation of a content-rich environment for engineering education. Multiple simulations were developed for specific engineering topics. They were tied together by the 3D virtual world. Each simulation can be used to deposit a specific 3D structure in the virtual world. For instance, the simulation of structural analysis can be used to create a bridge, and the bridge can be deposited in the virtual world. Collaborative learning, and the encouragement of creativity and teamwork are achieved through the collaborative design and analysis environment. Users in different locations can discuss a design problem through the use of the Internet. Furthermore, three assessments were conducted to evaluate the effectiveness of the environment. For example, 17 students used the collaborative design and analysis environment to finish an assignment of optimizing the weight of a beam subject to the stress. A survey was conducted afterwards and its data were analyzed statistically.

Chapter 3: Essential Elements of the Environment

3.1 Fundamental Elements for Distributed Collaborative Design

To develop a collaborative environment for engineering design and analysis, it is important to identify its fundamental features derived from the expectations of the end users. Different researchers may have different viewpoints, but this research focuses on the discussion of essential features, such as sharing information, natural communication, manipulation of design objects, database management, generation of design documents, intelligence, guaranteed real-time delivery, security, and scalability.

3.1.1 Sharing Information

It is vital for authorized users to share the latest information and access the previous information in a distributed design environment [74, 75, 76]. Design information not only includes text descriptions of current design status but also engineering information such as 3D models, engineering drawings, and analysis results. In engineering design, the sharing of 3D models is particularly important because it is the best way to present the design objects. Since the design objects are continuously being updated while the design is going on, the environment should ensure that the users always obtain the latest design information. If the users want to review a previous version, they should also be able to access it seamlessly. Also, to decrease Internet response time, it is critical to share commands instead of the full generated data. It is not efficient to transmit large volumes of generated data over the Internet to update each remote computer, but a command is small, which can be used to generate the data on the local computer using the local CPU.

3.1.2 Natural Communication

Since design is essentially a collective work that requires many individuals to work together, it is important that a distributed environment is capable of helping users work collaboratively. Collaboration is the core concept of concurrent engineering and the heart of team-based design [5, 6, 77]. To complete a design, negotiations among participants need to take place continuously. As the designers are geographically dispersed, the environment needs to create a naturally collaborative environment in which each authorized participant can communicate with each other without obstacles [78, 79]. For synchronous collaboration, it is ideal to provide a face-to-face virtual world where the participants can interact as if they were in the same room. For example, the participants in the virtual world can point to the same design object with verbal and nonverbal communication. Because different regions are in different time zones, it is also important to allow the user to communicate asynchronously.

3.1.3 Manipulation of Design Objects

To collaborate efficiently in a synchronous way, the collaborative design environment should not only create a virtual world for natural communication but also provide the capability for participants to manipulate the same design object simultaneously [79]. Whether the design object is a 3D model or a 2D drawing, when one of the participants is manipulating the design object other dispersed participants should see the action of the manipulation. If someone else makes a change to the design object, others should see it immediately on their own computers. This is an essential feature for synchronous collaboration.

3.1.4 Database Management

A database-management system (DBMS) should also be used to record design information and keep the latest and previous design and specifications [75, 80, 81]. There are numerous reasons for using a DBMS. First, a DBMS does not have concurrent-access anomalies. This is important because many users may access the data at the same time. Second, it can remove data redundancy and inconsistency. In a distributed multi-user environment, it is unwise to keep multiple working copies of the data, because what starts as the same data may disagree over time. Third, a DBMS can reduce the difficulty in accessing data. As the database keeps all of the latest information related to the design, the user can obtain any information from the database efficiently and conveniently. Also, the user can search the database for specific information, which includes documents regarding critical design decisions, specifications, and analysis results. Fourth, using a DBMS, it is easy to enforce security constraints on different users compared to a conventional file-processing system. Finally, it can ensure data transaction to be atomic, which means the data transfer must happen in its entirety or not all.

3.1.5 Generation of Design Documents

As many participants may work on the same design object, the environment should automatically record who makes the change when changes occur [82, 83]. When a critical design decision is made, the environment should remind the participants to provide the reasons supporting this design decision. This design document should be stored along with other design document and 3D models as a part of the design object. This is extremely helpful when a design object needs to be redesigned or a similar design needs to be completed in the future. In this case, future designers can search information of similar designs. There is no need for them to spend time in tracking related documents. Carefully generated design documents will encourage reusing the design knowledge and increase the productivity of the designers.

3.1.6 Intelligence

A distributed design environment should be an intelligent design support system [76, 79, 80, 83]. Due to the distribution of the participants, the environment should be able to automatically process routine work such as notifying all of the interested participants when a critical change happens to a design object. The environment should guarantee that this notification is read by all of participants in time. If someone disagrees with the change, a meeting should be scheduled through the use of the collaborative environment. The core argument should be recorded along with the design object for future review. As design knowledge is routinely captured, the environment should be able to provide knowledge support to the designer when similar designs are available. If knowledge support of the environment is efficient, the development cycle of products can be shortened.

3.1.7 Guaranteed Real-time Delivery

A distributed collaborative environment is a real-time application, which is different from traditional data applications such as Telnet, FTP, and Web browsing. This requires the quality of service from the Internet to be high so that lag time is minimized [93]. The packets sent should reach their destinations in a specified time interval, for instance, 100 ms. This also requires that Internet to promise guaranteed packet delivery since it is unacceptable for packets sent by one user not to reach their destinations.

Currently, the Internet only implements a best-effort service model, which tries its best to deliver the packets but without any guarantee. The Internet with necessary quality of service may be available in the near future [93].

3.1.8 Security and Scalability

In a distributed design environment, privileges should be limited to needs of the users [71]. Some should be only allowed to view the general information such as the outer shape, while others should be allowed to see the detailed design. Data transferred over the Internet should be protected carefully to prevent sensitive information from being compromised [80]. Security strategy is critical to the success of distributed design environments, because no company will adopt a distributed environment that does not protect sensitive information sufficiently. As the number of the participants is constantly changing, a distributed design environment should allow scaling while maintaining an acceptable level of performance [81].

3.2 Fundamental Elements for Internet-based Engineering Education

Ideally, the fundamental elements for Internet-based engineering education should include interactivity, collaborative learning, 3D visualization, and encouragement of creativity and teamwork. This is because with these key elements Internet-based engineering education is more effective. The following sections will discuss how these elements associate with the Internet-based engineering education.

3.2.1 Interactivity

Interactivity helps students better understand course materials presented on the Internet by allowing students to explore engineering concepts [45, 49, 50, 51]. An

Internet-based educational environment should not present just the course materials using text, graphics, sound, and video. It should also provide interactive simulations in which students can explore what they have learned in classes and obtain immediate feedback. For example, when students are learning to compute the deflection of frame structures, it would be particularly helpful if students can draw frame structures, apply forces, determine the deflection, and then compare their solutions with computational results. If their original solutions disagree with the computational deflection, the students can investigate why their solutions are incorrect. In this case, interactivity helps students grasp deflection calculation of frame structures.

3.2.2 Collaborative Learning

Just as collaboration is essential in the process of product development, collaborative activities are also important in the learning process [84, 85, 86, 87]. An Internet-based educational environment should allow dispersed students to study together while taking Internet-based courses. For example, when a student is unable to solve a statics problem using the learning environment, a teaching assistant should be able to show the student the procedure through drawings and explanations. When the teaching assistant draws a structure and applies a force, the student needing help can see each step as the solution progresses, not just the final diagram. Collaborative learning is particularly beneficial to students taking distance courses, because it is difficult for these students to meet and discuss the course problems.

3.2.3 Three-dimensional Visualization

The best way to be successful in demonstrating engineering concepts, especially in mechanical and civil engineering, is to use 3D models illustrating engineering concepts [88, 89, 90]. Through 3D visualization, complex concepts can be explained without a lot of words. Students can also obtain a direct impression of the 3D models, which is even more useful if 3D models can be changed and created by the students.

3.2.4 Encouragement of Creativity and Teamwork

An Internet-based educational environment should not only present the course materials but also should inspire creativity and encourage teamwork [91]. The creative work done by students should be published in the educational environment where other students can see it. An Internet-based educational environment should encourage team spirit, because teamwork is the core idea of concurrent engineering in product development. In such an environment, dispersed students should be able to discuss and work on group projects synchronously or asynchronously, and therefore complete the projects jointly.

3.3 Implemented Elements in the Virtual City

Generating design documents, intelligence, guaranteed real-time delivery, security, and scalability are not the focus of this research. This is because generation of design documents and intelligence are usually the research focus of design support systems while security issues and scalability as well as quality of service are in the realm of computer science. The Virtual City focuses on sharing information and manipulation of design objects as they impacts engineering design and analysis. Communication is achieved by providing real-time text-based discussion. Natural communication is not considered because it requires expensive hardware and a high Internet bandwidth. A database is used to manage the data of the Virtual City. These features can combine to create a shared understanding of the design object in a distributed collaborative environment.

Since an Internet-based distributed collaborative environment also supports interactivity, collaboration, 3D visualization, and teamwork, it is particularly suitable to use it as an engineering educational environment. The Virtual City contains nine interactive multimedia modules to emphasize the interactivity. The modules simulate specific engineering concepts and are seamlessly integrated into the Virtual City through the use of a 3D virtual world.

Chapter 4: Design of the Virtual City

4.1 Introduction

The Virtual City is a framework for engineering education, collaborative geometric modeling, and collaborative engineering analysis. It provides an Internet-based engineering educational environment with rich content, and it allows dispersed users to perform geometric modeling and engineering analysis jointly through the use of the Internet. The architecture and layout of the Virtual City are discussed in the following paragraphs.

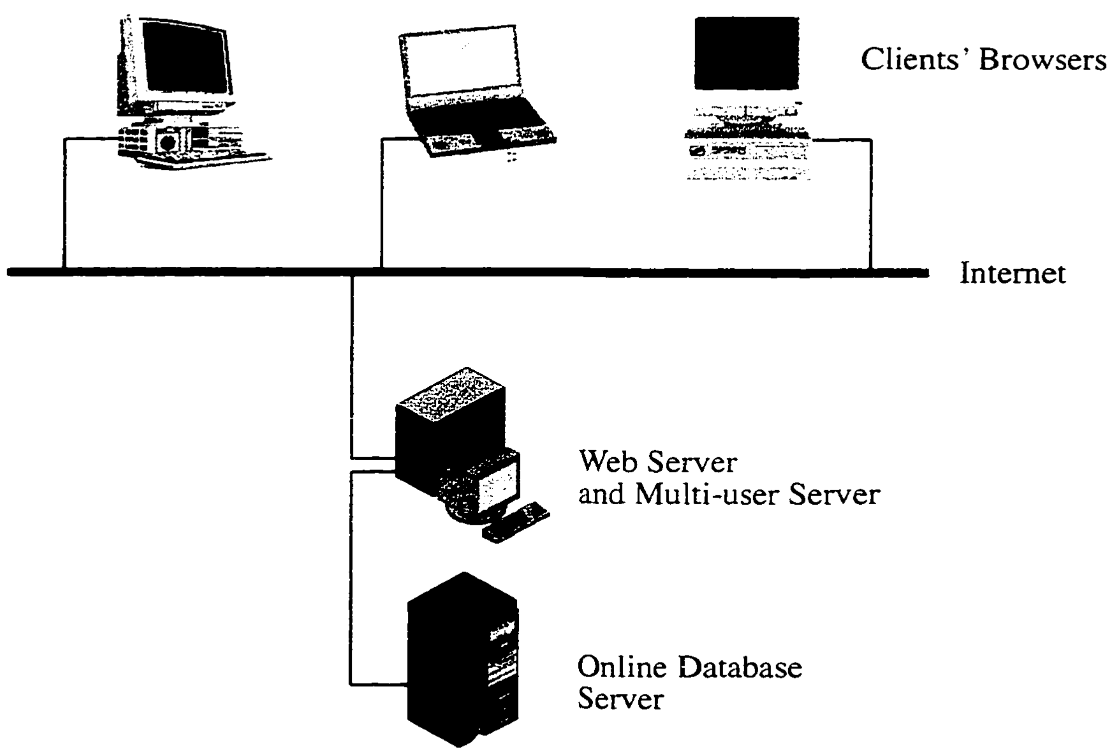


Fig. 4.1 Three-tier Architecture of the Virtual City

A three-tier architecture is employed in the development of the Virtual City (Fig. 4.1) that contains an online database server, a Web server with multi-user servers, and the clients' browsers. Volatile information is managed by the online database management system. The Web server works as middleware to take data from clients and store the data in the database. It also retrieves data from database and presents the data to the clients. Static information, such as description of engineering topics, is stored directly on the Web server. The multi-user servers manage the communication between clients and are independent from the Web server. As no dedicated computer was available to hold the online database when the Virtual City was implemented, the Web server, the multi-user server, and the online database server are located in the same computer. However, the concept of implementation is still the same as the three-tier architecture.

The actual Virtual City is composed of five components: a 3D virtual world, the Internet-based multimedia modules, an online database, a collaborative geometric modeling module, and a collaborative engineering analysis module (Fig. 4.2). A key component of the Virtual City is the 3D virtual world that contains various structures. These structures are created and deposited by corresponding multimedia modules that make up the second component of the Virtual City. Different multimedia modules are tied together by the 3D virtual world. Each multimedia module covers a specific engineering topic. A SQL database is utilized to manage volatile information such as user account information and design information. The collaborative geometric modeling module can be used to design simple structures that are deposited into the 3D virtual world. The collaborative engineering analysis module is a natural extension from the geometric modeling that can read data from the geometric modeling module, conduct typical 3D finite element analysis, and display the stress results in color, all over the Internet.

Fig. 4.2 Overview of the Virtual City

4.2 Three-dimensional Virtual World

The Virtual City implements an Internet-based 3D virtual world with a true 3D perspective. Students are allowed to build segments of the 3D virtual world upon completion of appropriate undergraduate courses in civil engineering. The end result is a complete virtual world that contains designs from all of their coursework, for example, a highway system, bridge, dam, building, or steel structures. The virtual world is viewable on the Internet and can be navigated by anyone over the web. The 3D virtual world is the key to the Virtual City and ties all of the other components together.

4.2 Database Management

The Virtual City uses an online database management system to manage all of the volatile data. This is because it is more efficient to save, update, and delete data in the database than in the text files. The changeable data include data of user accounts, data of team accounts, and data of generated structures in the 3D virtual world. To use the Virtual City, each user must provide necessary information to create an account, such as user account name and password. After creating an account in the database, the user can log into the Virtual City, explore the multimedia modules, create structures, and deposit them into his/her own 3D virtual world. Only an authorized user can log into his/her own individual account that contains his/her private 3D virtual world. In order to use the collaborative geometric modeling and engineering analysis modules, a shared team account must be created in the database. The team members can then log in the team account and use the geometric modeling module, the engineering analysis module, and multimedia modules. In the team account, only one shared copy of the 3D virtual world is stored but the number of structures in the shared 3D virtual world can be constantly changing, because structures can be designed, constructed and deleted.

4.3 The Virtual City for Engineering Education

One of the main purposes of the Virtual City is for use in engineering education; therefore it also focuses on interactivity, 3D visualization, collaborative learning, and inspiring creativity and encouraging teamwork. Interactivity is achieved by developing multiple multimedia modules that cover numerous engineering topics. In general, each multimedia module has two subsections. One is an information subsection that explains a specific engineering topic, and the other is a simulation that is designed to allow the user to explore the topic. The user is expected to study the information subsection and related materials carefully before they start exploring the simulation since the simulation assumes that the user has a basic knowledge of the particular topic. Flexible interactivity is always the central design concept of the simulations. The user can modify multiple parameters, and draw a truss structure, frame structure, or cross section as input information. The results of the simulation are then presented using animation, graphics, contours, and tables. Another key design concept of the simulation is intuitive interface, because ease of use is a required element for any product.

Three-dimensional visualization is difficult to implement over the Internet because of heterogeneous computer systems. However, it is vital to let the user see and work with 3D models in engineering education. Due to the introduction of VRML and Java 3D, it has become possible to present 3D models through the Internet. In the Virtual City, an Internet-based 3D virtual world is utilized to offer a central location to manage various 3D structures created by different multimedia modules. Structures in the 3D virtual world such as buildings, steel structures, bridges, highways, and dams are generated from different multimedia modules. The 3D virtual world therefore ties all of simulations together in one environment.

Collaborative learning and teamwork are difficult to integrate into the design of an Internet-based engineering educational environment, because server-side and client-side applications need to work together. However, as one of the main research objectives of the Virtual City is to implement a truly distributed collaborative environment, teamwork and collaborative learning are key functions of the Virtual City.

Inspiring creativity is always essential in engineering education. Generic modules are designed to achieve this. For example, the structural analysis module provides a generic truss/frame simulation that can perform analysis of any simple or complex truss and frame structure. The user can draw any kind of topological structure and apply any kind of valid boundary condition. The results can be obtained using finite element analysis. Minimizing the restriction on the user's input is one way to encourage creativity. The collaborative geometric modeling module is another example that allows the user to create flexible design objects and deposit them into a 3D virtual world.

4.4 The Virtual City for Engineering Design

The Virtual City is not only for engineering education but it can also be used for engineering design. The collaborative geometric modeling module is capable of sharing information, communication, and manipulation of design object, which are key elements for a distributed collaborative environment.

In general, the geometric modeling module is a simple CAD program that provides a generic general-purpose 2D drawing tool, 3D operations such as extrusion and revolution, and a rendering tool. However, it is different from traditional tools, because its internal design supports multi-user capabilities. Users in the same team can work on the same geometric object in different locations. Real-time information sharing and real-time manipulation of the same design object were implemented. Because it is difficult to implement natural communication features such as video over the current Internet due to the bandwidth limitation, only a real-time text-based chat room was developed for communication with this basic prototype.

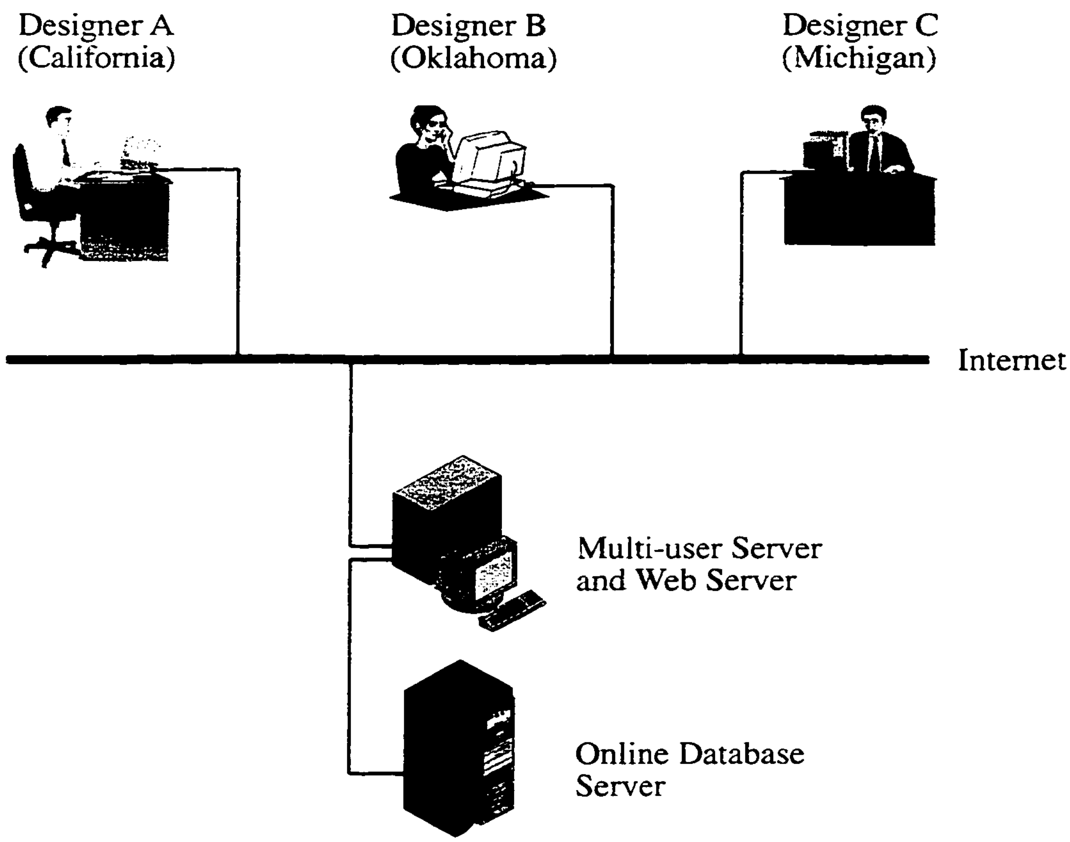


Fig. 4.3 Distributed Collaborative Design and Analysis

The collaborative geometric modeling module works as follows. Let's assume there are three designers in a design team. Designer A is in California; Designer B is in Oklahoma; Designer C is in Michigan (Fig. 4.3). First designer A and B log in the design environment. Designer A draws a line and Designer B sees it immediately; Designer B draws another line and thinks the location of first line is not good enough and moves the first line; then Designer A sees changes Designer B has made. Designer C then logs into the design environment, and joins the work of other two. Designer C immediately sees the work-in-progress from the other two designers. The main idea is that only one copy of the file is kept and the designers share the same design object. If Designer A disagrees with designer C, he can communicate with designer C through a chat room. After the cross section is finished, it can be extruded to obtain a 3D object. Then Designer C feels that it is difficult to produce this part and wants to discuss it with his peer designers. He rotates the object and his peer designers immediately see the part rotation on their own screen. Then they can discuss the production problem while viewing the object from the same point of view.

4.5 The Virtual City for Engineering Analysis

The same concept of distributed collaboration can be extended to engineering analysis. Similar to geometric modeling, the key elements to distributed collaboration such as sharing information, communication, and manipulation of design objects were implemented in the engineering analysis module.

The engineering analysis module is a CAE program that can conduct typical finite element analysis and visually demonstrate the computational results. The difference between the engineering analysis module and traditional CAE programs is that the module is Internet-based and supports multi-user features. This is the first engineering analysis tool to implement distributed collaboration. When in the investigation stage, this type of analysis tool was not found to have been developed by any other researchers. The engineering analysis module can import the geometric data generated by the geometric modeling module and display it in wireframe. The user then can specify the material properties and units for the imported geometric model. Automatic meshing was developed to prepare the data input for finite element analysis. The user can assign the number of elements associated with three edges to perform meshing. After the meshing is over, boundary conditions, point forces, and/or distributed forces can be applied. Two kinds of elements were used in the engineering analysis. One is a tetrahedral element and the other is a hexahedral element. The user can select the preferred element. The last step is to conduct computation and check the visual results or read the result report.

The engineering analysis module is just a prototype to demonstrate the concept of collaborative engineering analysis. It is not simply a full, commercial finite element program. One of its limitations is that it can auto-mesh only geometric objects with six faces since the auto-meshing of an arbitrary geometric object was not implemented.

To illustrate how distributed collaboration works in the engineering analysis environment, let's assume there are three engineers in an analysis team. Engineer A is in California; Engineer B is in Oklahoma; Engineer C is in Michigan (Fig. 4.3). First Engineer A and B log into the environment and start the applets. Through a chat room, Engineer A discusses with B which file they need to work on together. Engineer B then loads the target geometric data file into her applet, and the same file is loaded immediately on the applet of Engineer A. Engineer A decides to assign the number of elements along three edges and perform automatic meshing to the geometric object. The meshing is propagated to the applet of Engineer B, and Engineer B sees the meshes. However, Engineer B thinks the meshing is not good and discusses it with Engineer A. Engineer B then deletes the previous meshing and conducts her meshing. The deletion and new meshing are propagated back to the applet of Engineer A. Engineer C then logs into the environment and starts the applet. As they all log into the same team account, Engineer C immediately sees the work-in-progress from the other two engineers. After they finish working on the boundary conditions and forces, one of them starts the computation and the computation command is propagated to the other two engineers' applets. All of them obtain the same computational results, and they are able to discuss the results by visually sharing the same viewpoint. For example, say, Engineer C wants to discuss von Mises stress with the other two engineers. He selects the von Mises distribution on his applet. The other two engineers instantly see the same demonstration on their own screens. If Engineer C wants to investigate the analysis by himself, he can temporally leave the team. In this case, any action by other two engineers will not be propagated to him, and his behavior will not affect the analysis conducted by the other two engineers. Engineer C is disconnected from other two engineers. If Engineer C joins the team again, he will lose whatever is on his applet and obtain a copy of the work-in-progress of the other two engineers.

Chapter 5: Implemented Technologies of the Virtual City

To develop the Virtual City framework, numerous Internet technologies were employed, including Hypertext Markup Language (HTML), JavaScript, Director Shockwave, VRML, Java, Java 3D, Active Service Page (ASP), Structured Query Language (SQL), Perl, and the SQL online database. These technologies were chosen because they are well defined and commonly used at commercial web sites. They were utilized together and programmed so that they can communicate smoothly with each other. For example, ASP and the online database work together to generate VRML virtual worlds dynamically, and Shockwave and Perl talk to each other to create new virtual structures. This is a unique feature of the framework since these various technologies together form the basis of the Virtual City. In addition to these technologies, numerous multimedia applications, such as Flash, Premiere, Photoshop, Freehand, and Dreamweaver, were employed to develop the framework.

5.1 HTML and JavaScript

HTML is the basic vehicle that delivers text information over the Internet. Other Internet technologies are used to add interactivity, animation, and 3D worlds to the basic HTML pages. HTML is a tag-based document formatting language, which can be read by any web browser. It is relatively easy to update HTML pages, because only one copy of the information is kept on the server and all users view the same page. All of the information sections of the multimedia modules were created using HTML.

Although HTML is good at delivering static text information over the Internet, it cannot be used to distribute dynamic information. JavaScript was used to add interactivity to the HTML pages [92]. This interactivity includes dynamically generating content in HTML pages, controlling the browser, and transferring information among HTML pages. The page content can be based on user input, which makes HTML pages distinct from traditional books. In the Virtual City, JavaScript was used to transfer the user ID among pages. Hence, the user only needs to provide the user ID once. JavaScript was also employed to transfer data among the HTML pages, and Shockwave simulations therefore read the data. Appendix A demonstrates the use of HTML code with JavaScript.

5.2 Shockwave and Multi-user Server

JavaScript is excellent in adding text-oriented interactivity to static HTML pages. However, it is difficult to use JavaScript to perform complicated, graphic-oriented simulations. To construct simulations over the Internet, other technologies can be employed such as Shockwave. Macromedia's Director was used to develop Shockwave simulations. A Shockwave simulation can be embedded into HTML pages. The user can then play the Shockwave simulation in the browser with a Shockwave player, which is now bundled with Internet Explorer and Netscape. If the Shockwave player has not been installed, the user will be alerted and prompted to install it. This auto-installation is particularly convenient when distributing the Shockwave simulation to remote users.

Shockwave is graphic-oriented, so it can be used to develop applications with complicated static and dynamic graphics. It has a built-in programming language called Lingo. Lingo is powerful in providing interactivity and controlling the graphics. Also, vector-based graphics are supported in Director Shockwave and can be controlled by Lingo. Because the graphic can be generated and deleted dynamically, the file size of a Shockwave simulation can be reduced dramatically. Numerous multimedia modules in the Virtual City employed this vector-based technique extensively. For instance, the consolidation module used the vector-based graphic to represent the time-based change of effective stress during consolidation. Another good example of using the vector-based graphic is the structural analysis module, in which topologically different 2D truss and frame structures can be drawn dynamically and then analyzed. Besides controlling graphics, Lingo was used to perform other complex numerical computations such as finite element analysis. Shockwave is not a stand-alone technology without communication with others. Shockwave simulations can obtain environmental parameters from HTML pages. These parameters could be dynamic data passed into the simulations. Similar to other Internet technologies, Shockwave supports the server/client model. This model allows the client to communicate with the server by CGI programs. Because of these, Shockwave is a key technology used to develop multimedia modules. The multimedia modules in the Virtual City have used Shockwave technology in unique ways to enhance engineering education. Some examples are foundation, consolidation, structural analysis, and piping network modules.

In addition to client/server capabilities, Director provides a Shockwave multi-user server for developing multi-player applications. The multi-user server links numerous Shockwave simulations through the Internet and usually is used to develop Internet-based multi-player games. The Virtual City borrowed the idea of Internet-based multi-player games and implemented the distributed collaborative concept in geometric modeling. The Shockwave multi-user server is a standard component of Director, which runs on the server and delivers messages between different Shockwave simulations on each user's browser. Special communication codes were used to implement the multi-user concept in the Shockwave simulations.

5.3 VRML

Shockwave is good at performing 2D simulation, but it is not strong in 3D. In order to present a 3D world over the Internet, an efficient 3D modeling language is needed. (It should be noted, however, that Macromedia is expected to incorporate 3D capabilities into Director Shockwave in the near future.) For these purpose, VRML was a good choice for the Virtual City, because it is a platform-independent, international standard for viewing 3D worlds over the Internet. VRML supports interactivity, animation, modification, and hyperlinks, which make it suitable to navigate 3D worlds. VRML uses text to describe the 3D model, allowing VRML files to be edited in any text editor. Furthermore, other programs such as Perl and ASP scripts can generate VRML files dynamically.

In the Virtual City, the 3D virtual world is constructed using VRML. Except for the standard ground that is the same for all users, Perl scripts dynamically generate all of the other structures in the 3D virtual world (Fig. 5.1). First they take the data from the Shockwave simulation, and then Perl scripts interpret the data and generate the VRML files based on the received data. The 3D virtual world is generated by an ASP script, which takes the data from the database and dynamically presents the world to the user. VRML is usually used to describe a fixed 3D virtual world. However, with the help of Perl, ASP, and the online database, VRML can be utilized to present a highly dynamic 3D virtual world (Appendix C). The research of the Virtual City thus widens the technical horizon of the VRML.

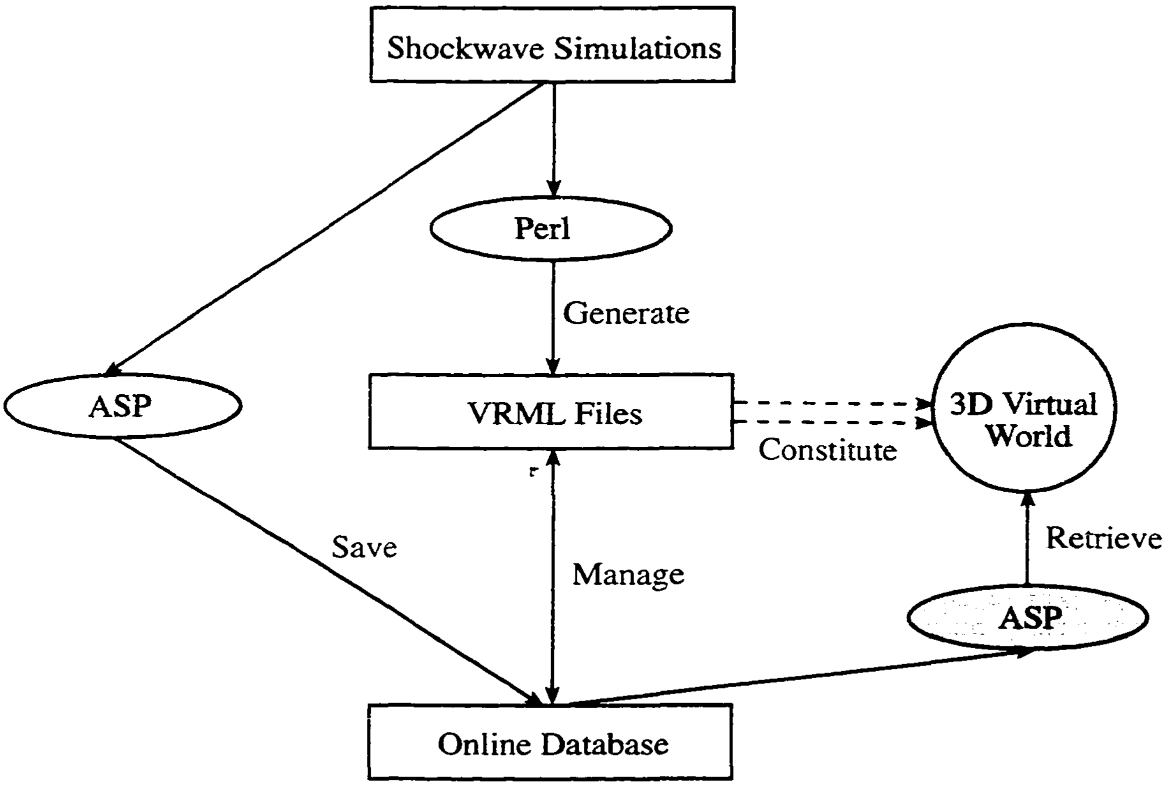


Fig. 5.1 Generation and Management of the 3D Virtual World

5.4 Java and Java 3D

VRML is excellent in presenting static 3D objects over the Internet. However, it needs the help of other programming languages to create dynamic objects and conduct complex computation. To create dynamical geometric objects, other languages with full capabilities are needed, such as Java and Java 3D.

Java is a general-purpose programming language similar to C++. The key features of Java are: simple, object-oriented, multi-threaded, robust, high-performance, secure, platform-independent, portable, and network supporting. Java is simple, because it follows the basic syntax of C/C++ but eliminates difficult concepts such as pointers. Programmers familiar with C++ can learn it easily. Java is a strong object-oriented programming language, which inherits the object-oriented concepts of C++. To create multi-task applications, Java allows for the creation of multi-thread processes in one application. Java does not allow using pointers and conducts garbage collection automatically, which eliminates the task of memory management and therefore makes Java robust in application design. The performance of Java has been improved and can compete with C++ due to the introduction of new technologies such as Java HotSpot and Just-In-Time compiling. These features make Java an excellent programming language for application development. A large number of commercial applications on the market have been designed using Java. Java is good not only for stand-alone applications, but also for Internet-based applications – Java applets. Java is designed for the Internet, so it guarantees the security of Java applets at a programming language level. It imposes strict security strategies on the Java applets, because applets are executed on the client machines. Java assures platform-independence through a Java virtual machine. As Java implements different Java virtual machines for different platforms, the Java applications and Java applets can execute without any change on different platforms. This eliminates the portability problems of C/C++. Java provides high-level support for networking. So it is particularly suitable to use it designing distributed collaborative applications, such as the distributed collaborative geometric modeling and engineering analysis of the Virtual City. Another powerful feature of Java is that objects can be serialized for transmission over the Internet. This feature can facilitate the development of distributed collaborative applications, because it makes easy to read the transmitted information. The programming necessary to data management can be dramatically reduced. The distributed collaborative engineering analysis employed this object serialization technique extensively.

To design a geometric modeling application using Java, a 3D application programming interface is needed, which is Java 3D. Similar to OpenGL, which is a platform-dependent 3D application programming interface, Java 3D provides a 3D-related library to design 3D applications. OpenGL is not object-oriented while Java 3D is. Java 3D is a standard extension of Java, which works smoothly in a Java environment. When a Java 3D application is created, both Java 3D classes and Java classes are used. Java is used to design the user Interface and perform computation while Java 3D is employed to complete the 3D-related mathematical operations and rendering tasks.

Java and Java 3D were selected as a major technology to implement the distributed collaboration, because they support networking, 3D, and can be safely downloaded to run on client machines. The rendering task of the collaborative geometric modeling module is done by an applet designed by Java and Java 3D (Appendix E). Java and Java 3D were also used to design another applet, which is the first Internet-based distributed collaborative finite element analysis. A Java-based multi-user server was also designed to work simultaneously with the geometric modeling and engineering analysis applets to achieve the collaborative features (Appendix D). The functions of the Java-based multi-user server are the same as the Shockwave multi-user server. The only difference is that the Java-based multi-user server was developed specifically for the Virtual City while the Shockwave multi-user server is a general-purpose commercial program.

5.5 Perl

Client-side interactivity is not enough in the Virtual City. Server-side interactivity is also needed to allow data to be exchanged with the server. The Perl programming language is one of many languages that can perform functions of Common Gateway Interface (CGI). Perl can gather the data from HTML form pages or Shockwave simulations, process the data, and send the results back to the HTML pages or Shockwave simulations. As mentioned previously, Perl is used to generate the VRML files of structures dynamically in the 3D virtual world, which is a unique way to modify the 3D virtual world (Appendix G).

5.6 ASP and SQL

In addition to using Perl to provide server-side interactivity, ASP is another way to achieve this. ASP is different from CGI applications in that a small DLL file interprets ASP scripts. This DLL file resides in the same memory space as the Internet Information Server. ASP is based on VBScript programming language and can be used to generate HTML pages dynamically, process client's requests, and access the online databases. In the Virtual City, ASP is mainly used to insert data, search and update the database, and present the results in dynamically generated HTML pages. ASP is also utilized to present the searched results from the database to Shockwave simulations. An innovative use of ASP is that ASP dynamically generates a VRML 3D virtual world with the help of SQL statements. The unique feature of the Virtual City is that the same ASP script generates different virtual worlds based on various input. This tremendously reduces the task of managing the numerous virtual worlds of the users. ODBC is used to access the database server through ASP and SQL statements.

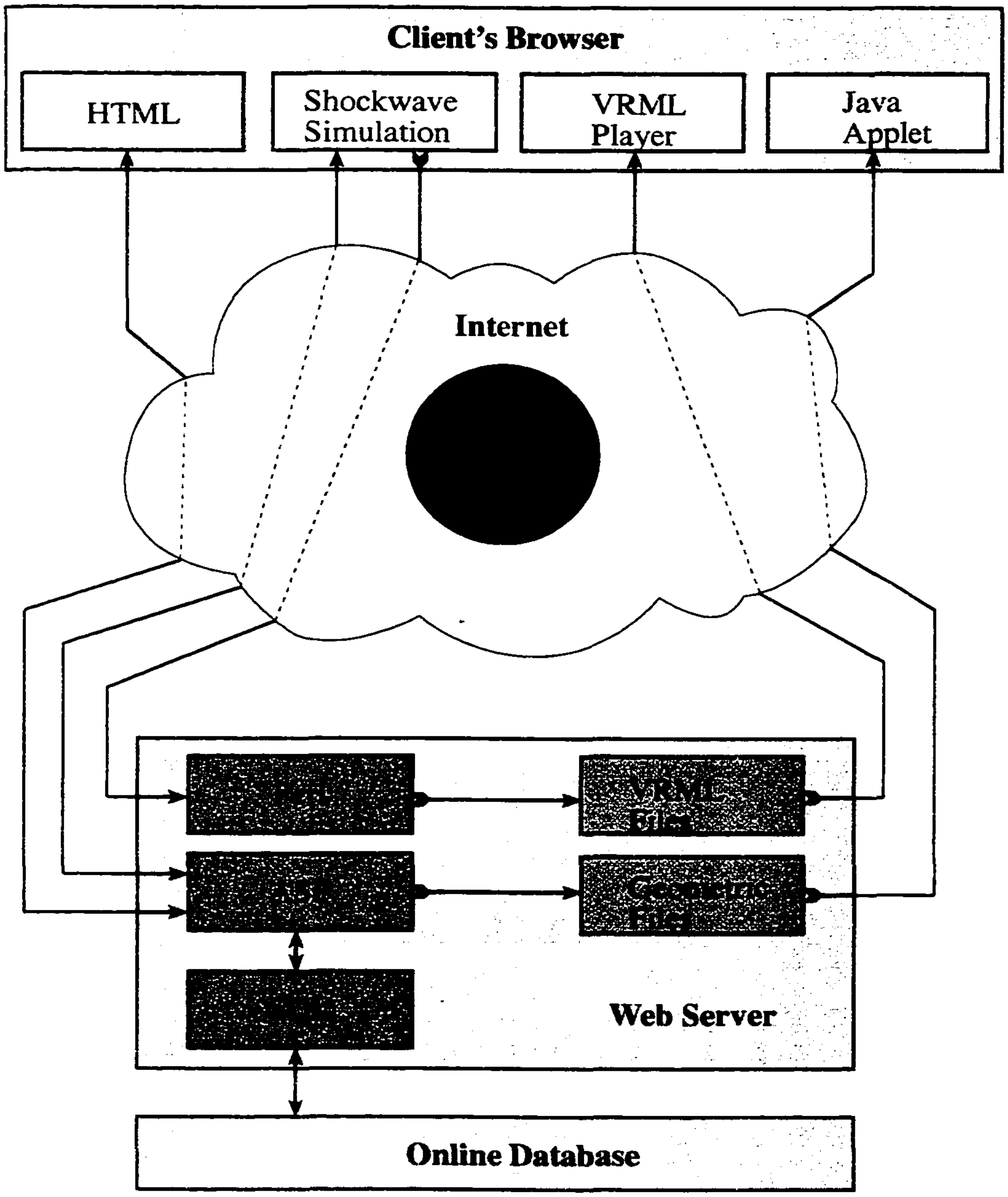


Fig. 5.2 Internet Technologies

SQL is a user-friendly powerful query language that utilizes a combination of relational-algebra and relational-calculus. Because of this, SQL works only with relational databases such as Access, SQL database, and Oracle. SQL is not just a "Query Language". It contains numerous features besides querying a database. For example, it can define the structure of the database, manipulate the data, specify security constraints, assure data integrity, and provide transaction control. In the Virtual City, SQL statements are embedded in ASP scripts to access the SQL database (Appendix H). The results are presented in text format or HTML format after the ASP scripts are interpreted.

Figure 5.2 demonstrates how these Internet technologies work together and how they communicate in the Virtual City. For instance, the Shockwave simulation accesses the online database through ASP, generates geometric files, and finally shades the geometric files through the Java applets.

5.7 SQL Server

ASP and SQL work with a database to manipulate the data. Numerous databases are available such as Access, MS SQL Server, Oracle, and IBM DB2. The Virtual City selected MS SQL Server as a central place to store data. This is because ASP can smoothly access MS SQL Sever. Another important factor is that it is easy to shift between Access and MS SQL Server without modifications of ASP files. MS SQL Server is a medium-size relational database and can be used for e-commerce and data warehousing. It supports all of the general requirements of a database, such as integrity, atomicity, concurrent access, and security. Because of these, MS SQL Server was chosen to manage the data of the Virtual City.

5.8 Internet Information Server

Besides the database server, the Virtual City also needs a server-side application called Internet Information Server (IIS) to publish information over the Internet. The general function of IIS is that it responds to the user's request with suitable information such as a HTML page, video clip, or multimedia simulation. IIS manages all data published publicly, and is the key application to allow users to browse the web site. In the Virtual City, Microsoft IIS was chosen due to its accessibility. Another reason is that ASP and MS SQL Server work seamlessly with Microsoft IIS.

5.9 Multimedia Applications

In addition to Director, numerous other multimedia applications were also utilized to develop the Virtual City. These multimedia applications include Flash, FreeHand, Photoshop, Dreamweaver, and Premiere. Flash is good at demonstrating animations with small file sizes. In the structural analysis module, multiple Flash animations were used to present truss concepts. FreeHand provides convenient drawing tools to create diagrams. It was used to design diagrams illustrating technical concepts. Photoshop is a standard graphics program, which can be used to change the color tint, remove backgrounds, add shadows, edit photos, etc. All pictures in the Virtual City were edited employing Photoshop. Dreamweaver is an advanced web page builder that lets the user construct HTML web pages without dealing with the actual codes. The information sections of the multimedia modules were constructed using Dreamweaver. Premiere is an excellent video edit program, which allows the user to splice together still pictures, movies and sound into a nice video. It was utilized to edit and compress a video clip illustrating traffic congestion due to poor ramp design in the traffic engineering module.

Chapter 6: Framework and Content of the Virtual City

The Virtual City consists of five components: a 3D virtual world, an online database, multiple multimedia modules, a collaborative geometric modeling module, and a collaborative engineering analysis module. The 3D virtual world contains structures deposited from multimedia modules. The online database manages dynamic data of the Virtual City. The multimedia modules illustrate specific engineering topics with the help of Shockwave simulations. The geometric modeling and engineering analysis modules implement the concept of distributed collaboration for design and analysis through the use of the Internet.

6.1 Three-dimensional Virtual World

The 3D virtual world is key to the Virtual City, because it provides an excellent way to tie various components, such as the online database, multimedia modules, and engineering design modules, together into one system – the Virtual City (Fig. 6.1.1). Also, 3D visualization is unique to this research, because, as of now, there is no Internet-based 3D visualization for engineering educational purposes. In fact, even desktop-based educational 3D visualization is rare. The following two sections will discuss the design of the 3D virtual world and its main functions.

6.1.1 Design of the Virtual World

The 3D virtual world was designed using VRML with the help of Perl, ASP, SQL, and the online database. These Internet technologies work together to generate its visual objects dynamically. There are two types of visual objects in the virtual world, as described below.

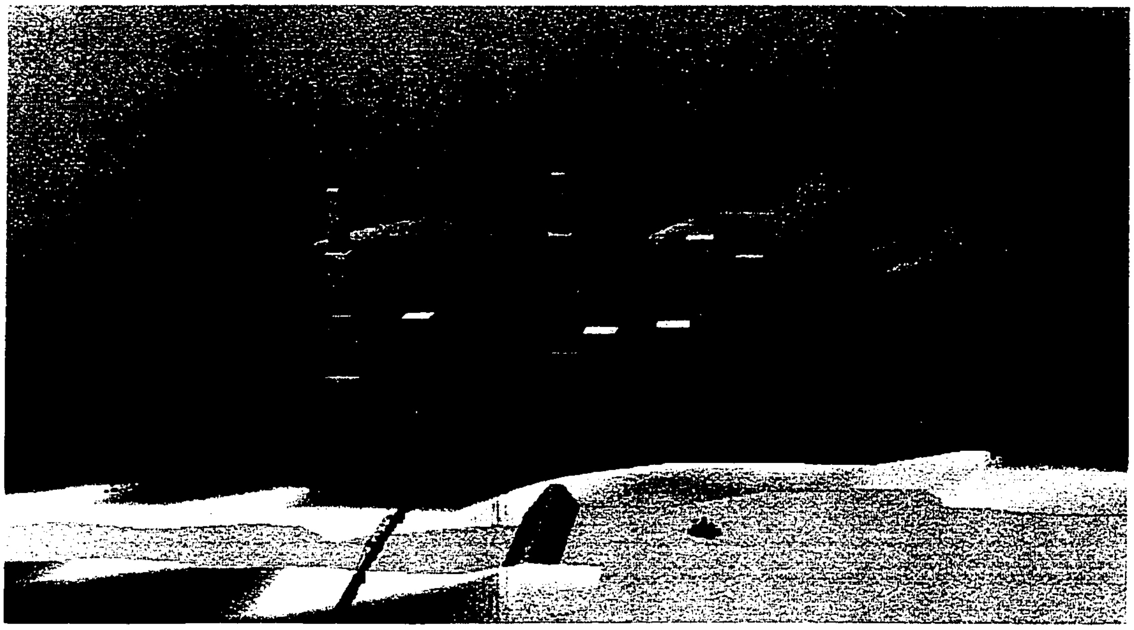


Fig. 6.1.1 Three-dimensional Virtual World

The first type of visual objects is a base ground, river, reservoir, and boat, as well as hills and numerous trees. These objects are geometrically fixed and serve as a basic platform for the virtual world. As they are fixed, these visual objects are pre-designed using a VRML authoring tool, and every user receives the same copy. The second type of visual objects is generated dynamically. Each user can create visual objects with different shapes or sizes. A coordinate system is used to determine the positions of the objects. The steps for generating objects are as follows. First, the Shockwave simulation is used to help design and prepare the data for particular objects. For example, designing a bridge requires data including section numbers, node positions, and the layout of the bridge. Second, the data is transmitted from the Shockwave simulation to the server. The server then starts a CGI-Perl program to take the data, and create an object in VRML format. The object can be seen immediately in the virtual world. Meanwhile, the data related to the object is saved in the database using ASP and SQL for later retrieval. Third, the user can modify the object by submitting new data. For instance, if the user dislikes the layout of the generated bridge he can modify the previous bridge by adding, deleting, or moving trusses and resubmit it to the server.

Besides using Internet technologies to create individual objects, the entire virtual world is dynamically managed by an ASP script with the help of SQL statements and the database. The virtual world is a customized world belonging to individual users. It is, however, inefficient and inconvenient to save multiple copies of the virtual world. One solution is to save only the customized parts of the virtual world and use a creative strategy to manage these customized parts. This strategy uses an ASP script to accept the data of the user account as input. Based on the input data, the ASP script then searches the database to retrieve virtual structures associated with that particular user and dynamically generates a virtual world. Using ASP, it is easy to set different default viewpoints for different simulations. This strategy is particularly efficient, because it can manage a large number of users. More sophisticated applications could be designed based on this prototype of the virtual world.

6.1.2 Functions of the Virtual World

The main function of the virtual world is to allow the user to see the 'big picture' using 3D visualization. Multimedia modules of the Virtual City can be used to build specific virtual objects that are deposited into the virtual world. For example, the traffic engineering module can be used to deposit a highway system and the structural analysis simulation to deposit a steel bridge. These modules are designed for appropriate undergraduate courses. When the student finishes these courses, a complete meaningful virtual world is also built. As the virtual world is built on the Internet, the student can demonstrate it to anyone with Internet access. This minimizes the difficulty of presentations with traditional design.

6.2 Online Database

The online database is a central place to manage dynamic data of the Virtual City. The reason a database was chosen to manage the dynamic data is that it is the most efficient approach to save, delete, retrieve, and search data. Similar to the design of conventional databases, the database design for the Virtual City is divided into four steps. The first step includes requirement collection and analysis. Collecting all possible functional requirements of the database is a crucial step of database design, because the rest of the design is based on this step. The relationships of requirements are then analyzed to eliminate redundancy. The next step is conceptual design. It is usually implemented by drawing an entity-relationship (ER) diagram based on logical relationships of the requirements. The third step is logical design. Tables are created based on the ER diagram, and the structure of the database is therefore determined in this step. The last step is physical design. The tables and their physical data structures are implemented in a specific database management system (DBMS). For example, MS SQL Server or Oracle may be used to design the actual database. In this research, MS SQL Server was selected as the DBMS, because it works seamlessly with other Internet technologies. The following sections will discuss these steps in detail.

6.2.1 Database Requirements

The requirements of the online database were collected from the Virtual City. There are two categories of accounts that need to be tracked in the database. Each user must have an individual account while several users may share a team account. To create a user account in the database, the user must provide a unique user account name, last name, first name, email address, and select a password for the account. The user is also asked to provide information such as occupation, major, and frequency of using online learning. The registration date is recorded when the account is created.

A unique team account name must be provided by the coordinator. The team account may have several members besides the coordinator. Members may share the team account, and the team account may have multiple geometric modeling files, multiple VRML files, or both. Each account manages the information associated with the soil, consolidation, steel, building, traffic engineering, and concrete modules. Each module contains a few data items. For example, the data items for the soil module include user ID, and values associated with the bottom, left, top, and height of a dam. When the user logs into the account, the database tracks the login ID, session ID, event type, client IP address, user agent, and the number of hits.

6.2.2 Entity-Relationship Diagram

Through analysis of the relationships of the above requirements, an ER diagram was drawn to demonstrate graphically the overall logical structure of the online database (Fig. 6.2.1). Such a diagram consists of rectangles, ellipses, diamonds, lines, double ellipses, double diamonds, double rectangles, and double lines. Traditionally, each component has a particular meaning [99].

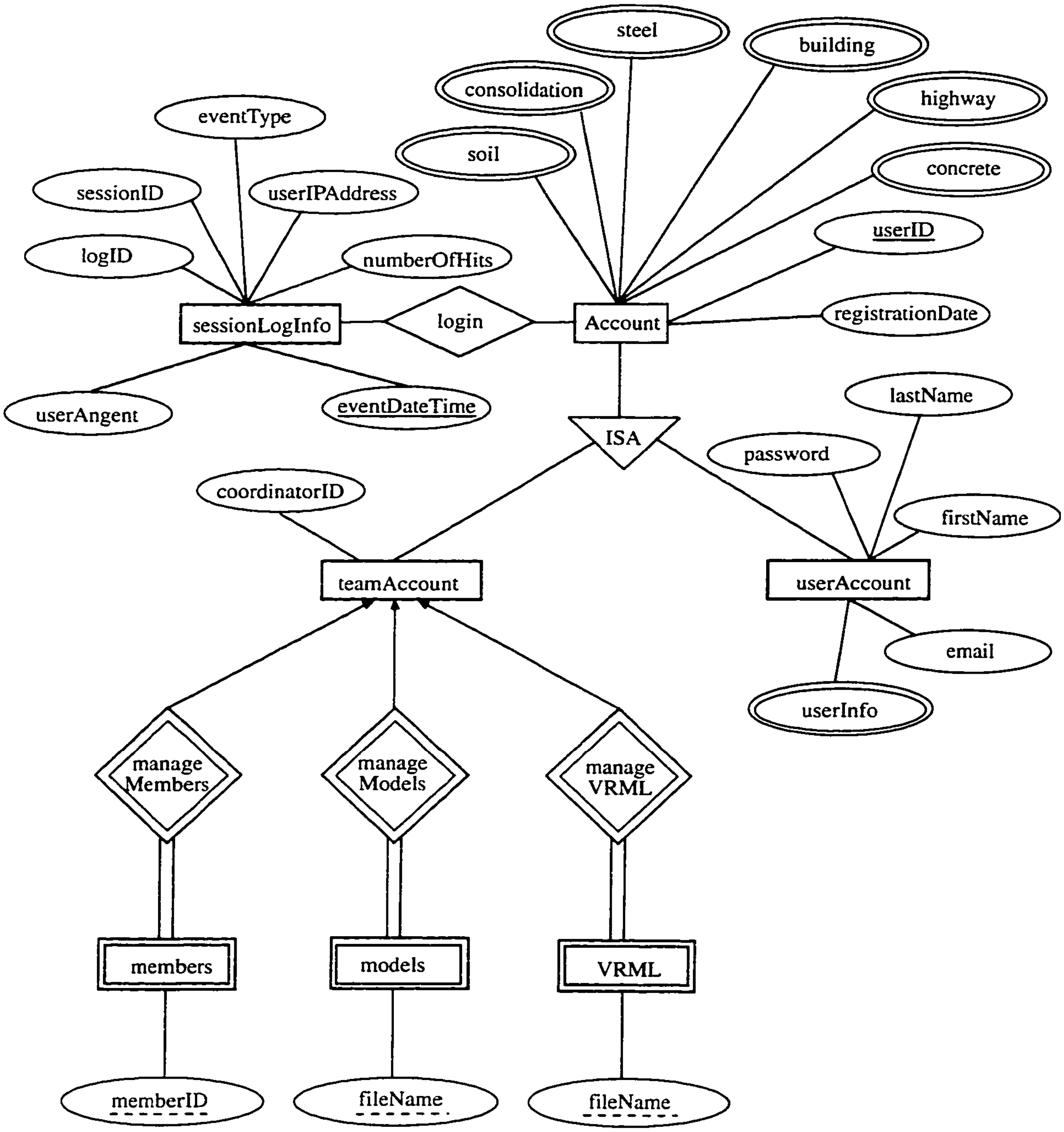


Fig. 6.2.1 ER Diagram for the Virtual City Database

6.2.3 Database Structure

From the entity-relationship diagram, a number of tables can be generated (Table 6.2.1). These tables are the logical data structure of the online database. An attribute with an underscore is the primary key that uniquely identifies a tuple in a specific table. Physical table design in MS SQL Server follows exactly the same data structure.

Table 6.2.1 Logical Data Structure for the Online Database

Number	Tables
1	UserAccount (userID, password, lastName, firstName, email, registrationDate, groupID)
2	UserInfo (userID, occupation, major, onlineLearning)
3	TeamAccount (teamID, coordinatorID, registrationDate)
4	TeamMembers (teamID, memberID)
5	TeamFolderFiles(teamID, filename)
6	TeamFolderVRMLFiles(teamID, filename)
7	SessionLogInfo (eventDateTime, eventType, userAccountID, sessionID, userIPAddress, numberOfHits, userAgent, logID)
8	Steel (userID, bayHeight, bayLength, bayWidth, noOfBayLength, noOfBayWidth, noOfBayHeight)
9	Soil (userID, damBottom, damLeft, damTop, damHeight)
10	Highway (userID, roadWidth, skyLineLaneNum)
11	Consol (userID, HoValue, landWidth, landLength)
12	Concrete (userID, beamNum, transparency)
13	Building (userID, height, leftRight, frontBack)

*Underscores indicate the primary keys of the corresponding tables.

6.2.4 Functions of the Online Database

The main purpose of the online database is to provide a solid method of managing data. There are three different types of data in the database. The first type is related to account management. This includes user account, and team account. The user may log in as an individual member or as a member of a team account (Fig. 6.2.2).

The second type of data is used to manage geometric parameters. These geometric parameters control the shape of the 3D objects that are deposited in the virtual world. The user may modify this data at any time.

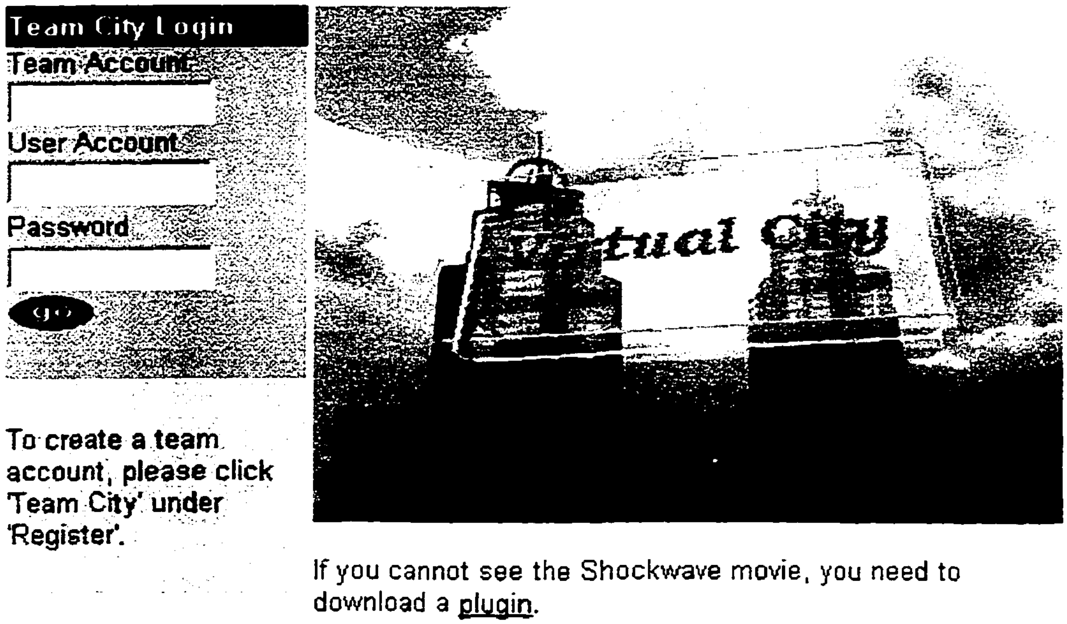


Fig. 6.2.2 Login System of the Virtual City

The third type of data is relevant to handling dynamic files created by team members. This type of data is more difficult to manage than the first two. Images, video clips, and text files are called irregular data, because the way of dealing with them is different from that of standard text and numeric data. There are two basic approaches for addressing irregular data. In the first approach, the irregular data are stored directly in the binary form. This is a relatively difficult method, but efficient. The second approach is to save the irregular data in a folder, and store their file names in the database. This approach is easier to implement and modify data outside of the database, and therefore the method the Virtual City uses to manage the geometric model files and VRML files.

6.3 Multimedia Modules

Multimedia modules are key elements of the Virtual City. Each module contains two sections: an information section and a simulation section. The information section covers the key engineering concepts related to the module. The simulation section is a Shockwave simulation that allows the user to learn engineering concepts through exploration. Most simulations are tied to the 3D virtual world by allowing the user to design and deposit a specific structure in the 3D virtual world. The finished modules are the traffic engineering, steel structure, surveying, foundation, soil, consolidation, structural analysis, concrete, and piping network.

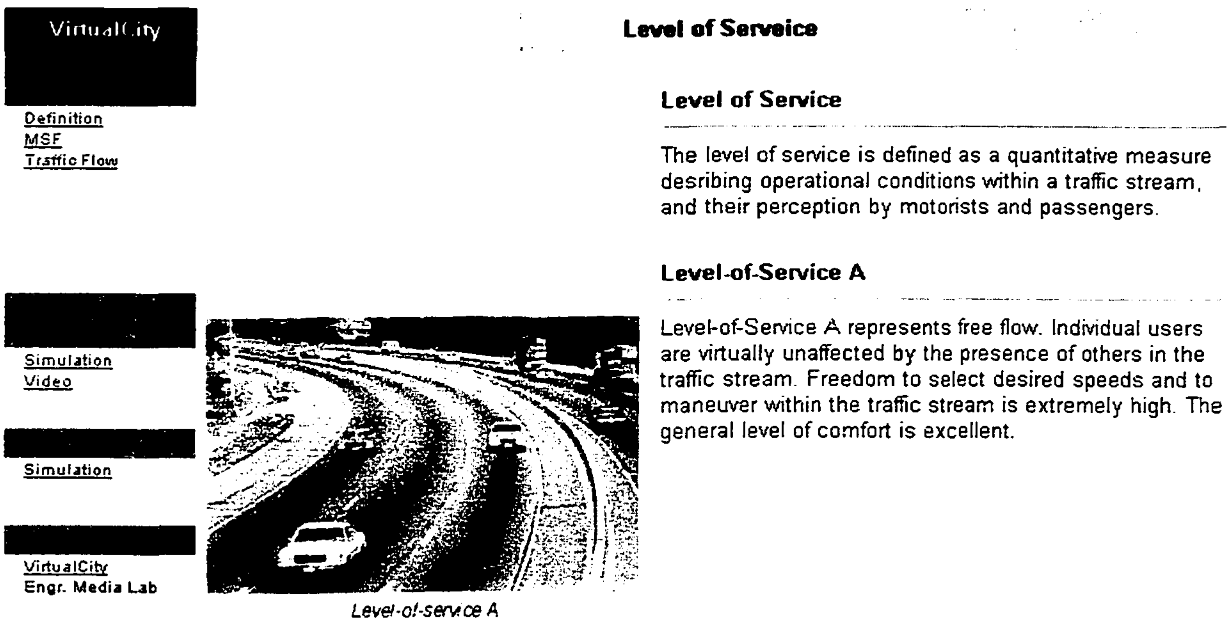


Fig. 6.3.1 Information Section of the Traffic Engineering Module

6.3.1 Traffic Engineering

The traffic engineering module was designed for the Introduction to Engineering course at the University of Oklahoma. As the course served freshman engineering students, only the basic concepts of traffic engineering were covered. There are three sections in the module. The first uses text and pictures to explain the definitions; the second is an interactive traffic simulation; the third is a video that demonstrates how the poor design of a ramp can cause traffic congestion. The highway system of the 3D virtual world is designed using this module. Figure 6.3.1 illustrates the information web page for the traffic engineering module. Other modules follow the same style.

The first section of the module covers the definition of the Level of Service (LOS) A, B, C, D, E, and F. Levels of service range from light vehicle traffic volume associated with unobstructed flow (LOS A) to extremely heavy traffic congestion (LOS F). Each LOS definition is accompanied with a picture to show the traffic volume visually corresponding to that level of service. Levels of service are defined by different levels of service flow in terms of vehicles per hour. In the vicinity of on-ramps, the highway maximum service flow values are reduced due to increased lane changes, weaving, and merging. For the sake of the module, the reduction in maximum service flow was made a function of the length of the acceleration lane at the end of the on-ramp. A table in the learning environment is used to give the reduced maximum service values for different acceleration lane lengths.

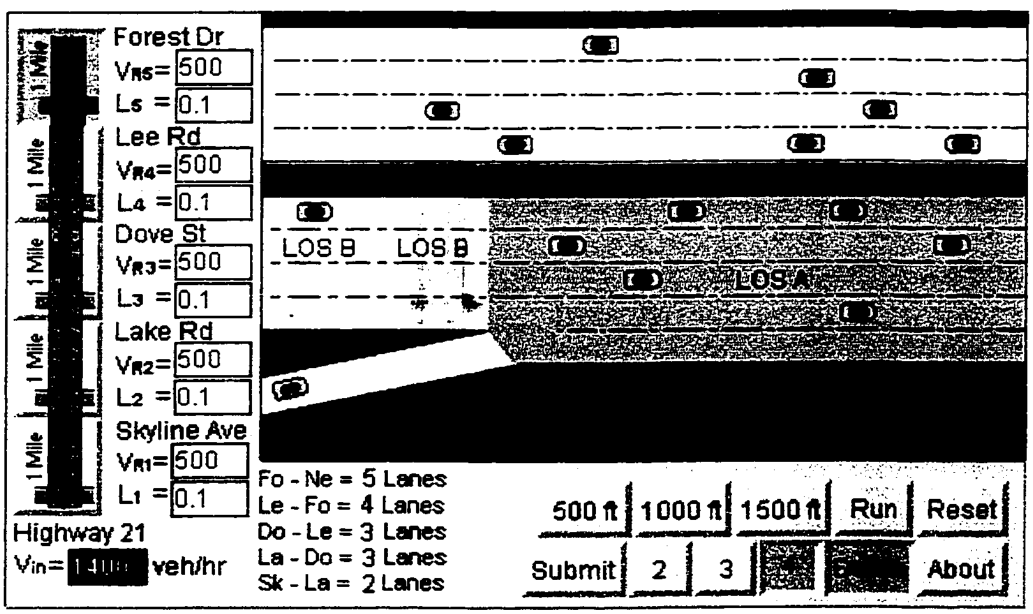


Fig. 6.3.2 Traffic Engineering Simulation

The second section of the module consists of a Shockwave simulation and explanatory texts. As mentioned in the previous section, the Director authoring tool was used to program the simulation. The exported Director file is a Shockwave simulation that can be distributed across the web. The purpose of this module is to demonstrate the concept of level of service visually.

There are thirteen features in the simulation (Fig. 6.3.2).

1. There are three lane configurations: 2, 3, and 4 lanes the users can select.
2. There are three choices for the length of the acceleration lane.
3. If the user wants to increase or decrease the number of freeway lanes, he can add or delete a lane.
4. There are five intersections available for design. Each intersection affects the design of the next one.
5. The level of service is illustrated using color shading based on the user's input of the traffic volume and the number of lanes. For example, if the current level of service is A, green shading appears. If the current level of service is D, the red shading is used.
6. The cost of an individual intersection and the cost of a total of five intersections are automatically calculated.
7. The number of the cars displaying on the freeway is based on the user's input. In this module, each multiple of 500 vehicles/hour is represented with a moving car. The maximum number of vehicles shown on the freeway is 16.
8. The velocity of the vehicles on the freeway has a relationship with the level of service. The velocity with level of service A is the highest.

9. If the total maximum service flow with only two lanes is more than 5,500 vehicles/hour, the vehicles on the screen will crash with sound effects.
10. The user can turn the sound on and off.
11. A photo is used to show a real ramp.
12. The current design configuration is outputted to the user during the session.
13. A message is used to prompt the user when there is a problem with the design.

The third section of this module includes a video of real traffic flow showing traffic congestion due to poor ramp design. As the file size of the video is large, video-streaming technology is used to play the video over the web. The latest Windows media player is also needed on the user's computer to play the video.

In engineering design, performance and cost need to be considered simultaneously. Therefore, when a student selects different design strategies, such as different numbers of lanes, the cost is also estimated. This helps reinforce the relationship between performance and cost to the students. After the basic traffic engineering concepts are introduced, the students are asked to determine the best design of the freeway for the given conditions. The design variables include the traffic flow rate, the number of lanes, and the length of acceleration lane. Students can choose the design variables by themselves, but they are not allowed to exceed a reasonable range of values.

There are numerous unique features in the traffic engineering module. It uses various colors to demonstrate different levels of service. The cars on the highway are moving with significantly different speeds at different levels of service, which gives a direct impression of the problem to the students. Although it is a simple design problem, performance and cost are considered simultaneously, which is an important concept for freshman students to understand.

6.3.2 Steel Structure

The steel structure module was designed for the Graphics and Design course at the University of Oklahoma and first used in the spring of 1999. Students who took this course used the module to help them understand the basic concepts of steel structures when they learned AutoCAD. The students were assumed to have little knowledge about steel structures, and only basic concepts were covered in this module.

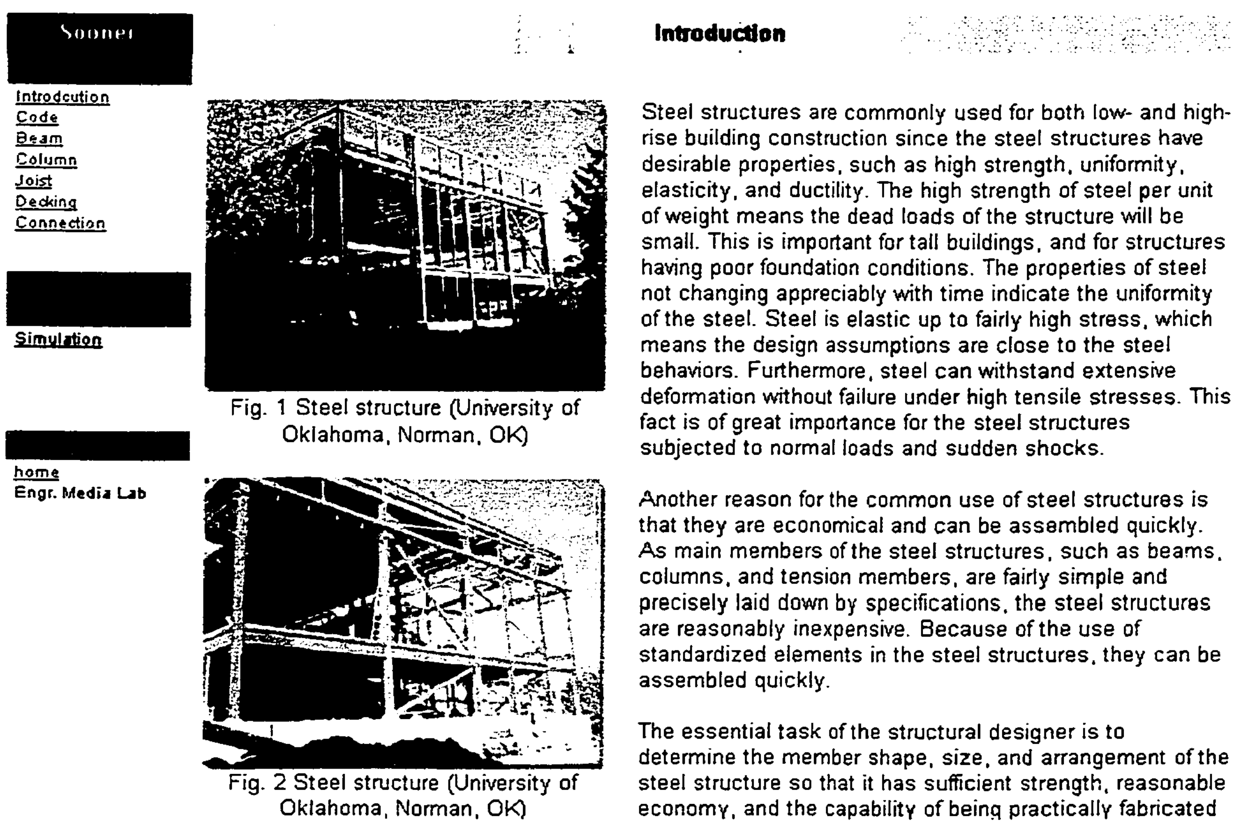


Fig. 6.3.3 Information Section of the Steel Structural Module

The information section includes seven subtopics - Introduction, Code, Beam, Column, Joist, Decking, and Connections (Fig. 6.3.3). Text, graphics, photos, and 3D models are used to present the concepts to the students. In these different media, VRML is used to present 3D connection models (Fig. 6.3.4). With VRML, students are able to navigate in the virtual world by rotating around and zooming into the connections, which allows them to see details of the connections. This technique is helpful in deepening the understanding of the connection structures.

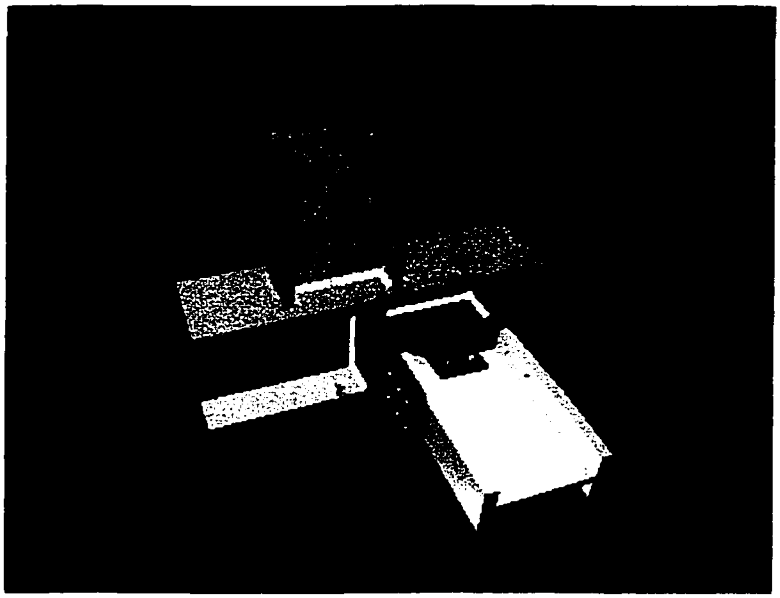


Fig. 6.3.4 Connection Illustration Using VRML

The Internet-based simulation (Fig. 6.3.5) of this module imitates the steps of designing a single bay steel structure. The purpose of this module was to provide an easily accessible tool for students to experience the design process for steel structures using the newly acquired knowledge. The main features of this simulation are as follows:

1. Building types, building size, live and dead loads, codes, safety factors and yield stress can be selected or entered.
2. Clicking on one of the two icons representing joists creates joists. The number of joists can be changed.

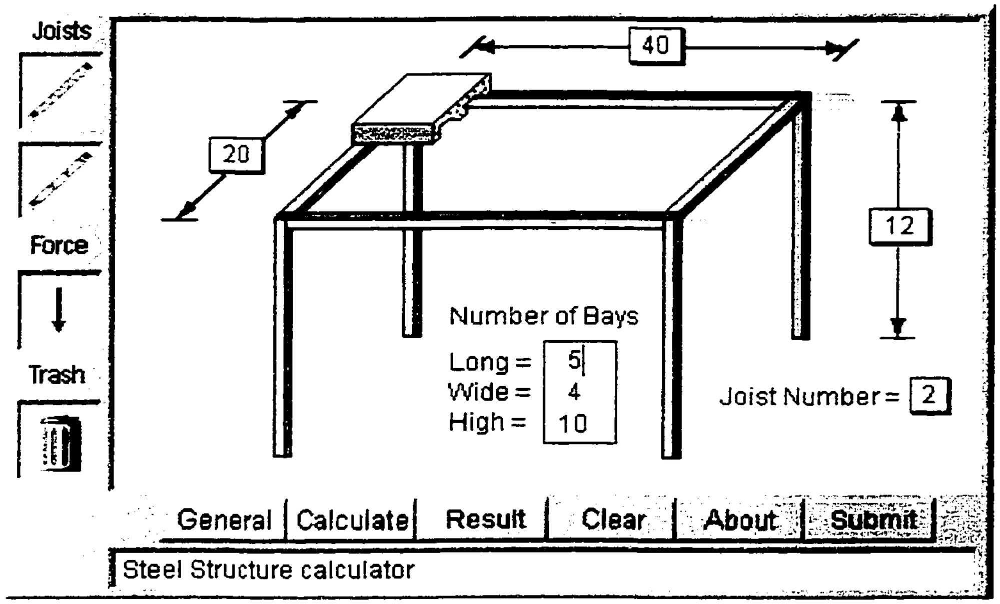


Fig. 6.3.5 Steel Structure Simulation

3. Clicking on the force icon generates a point force. The point force is moved by a "click-and-drag" motion and will snap to the beams or joists. The magnitude of the force can be modified by double clicking the force.
4. The type of beam or column can be selected through double clicking the specific beam or column.
5. Clicking on the 'Calculate' button performs the stress calculation. If the maximum stress of any member is larger than the allowable stress, the member is shaded red to depict failure.

6. If the "Results" icon is clicked, the stress results of members can be viewed.
7. The user can deposit a steel structure in the 3D virtual world if the "Submit" icon is clicked.

An important unique feature of this simulation is that a complicated steel structure can be designed dynamically in the 3D virtual world through the modification of three parameters (Fig. 6.3.6). The user can then view the details of how numerous bays connect with each other. Also, it can give the user an impression of 3D steel structures and stimulate their interests in leaning more about steel structures.

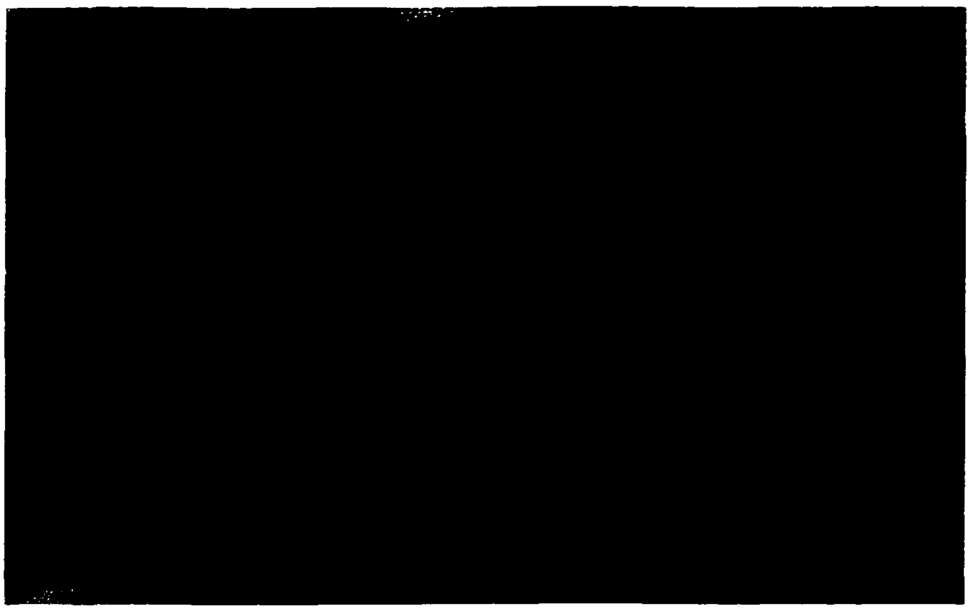


Fig. 6.3.6 Steel Structure Created by the Steel Structure Simulation

6.3.3 Surveying

The surveying module was designed for the Engineering Surveying course at the University of Oklahoma and used in the fall of 1999. The motivation for this module was to provide an Internet-based data processing tool for the Engineering Surveying course. Previously, to process surveying data, students used a specific software program to generate 2D contour plots. However, by integrating a number of Internet-based technologies, a surveying simulation could be developed to generate 2D contours and visually present 3D surfaces on the Internet. The idea of generating 2D contours and demonstrating a 3D surface at the same time was realized by integrating Shockwave and VRML technologies. CGI-Perl was also used to read data from the Shockwave simulation, generate a VRML file, and send the VRML file back to the user's browser.

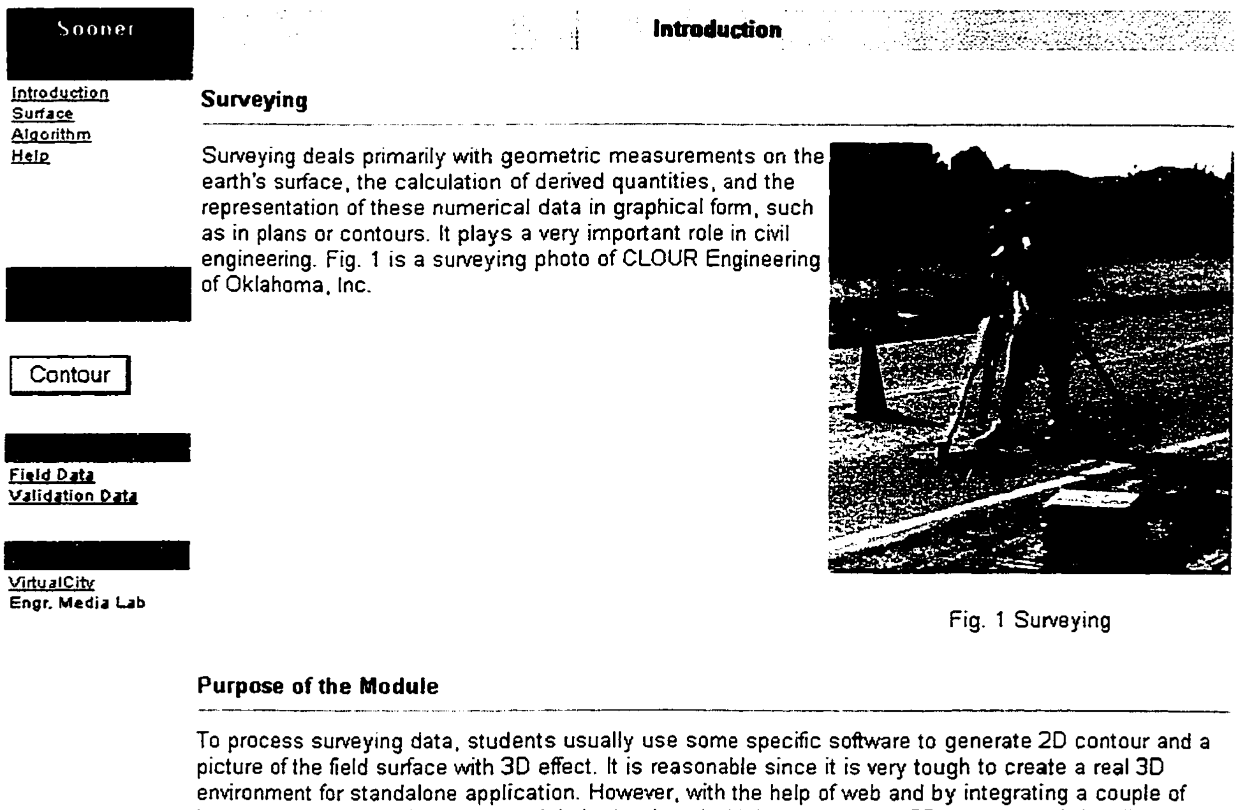


Fig. 6.3.7 Information Section of the Surveying Module

The design of the surveying module is similar to the steel structure, which also includes two sections: an information section (Fig. 6.3.7) and a simulation section. The information section contains three subtopics: Introduction, Surface, and Algorithm. Concepts related to the contour, and an algorithm, *Shepard's Method,* for the generation of the contours in the simulation were explained.

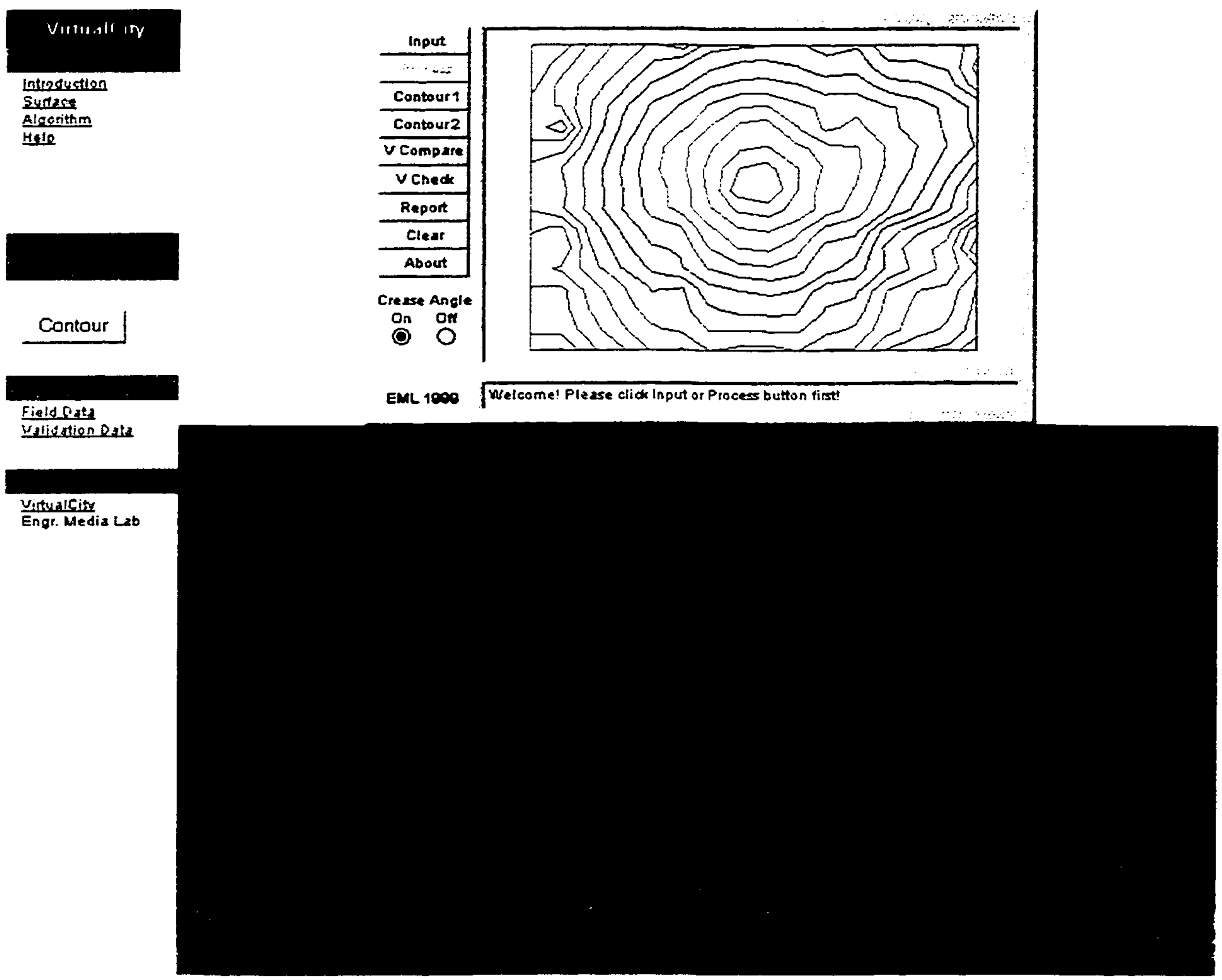


Fig. 6.3.8 Surveying Simulation

The simulation uses irregular field data, which is gathered by conducting surveys over an area. Because surveying points are irregularly distributed over the field, the resultant data are not uniform along the x and y direction. However, to plot the contour of the data, regular data has to be used, which means that steps in the data along x and y direction are uniform. *Shepard's Method* is employed to calculate the regular data points from the irregular data points. A contour-plotting algorithm is used to draw the contour, and a CGI-Perl script generates the VRML file on the server, which is shown on the user's browser (Fig. 6.3.8).

The users are able to upload their field survey data to the server because they have their own accounts on the server. They first browse their local hard disks and select desired files, and then click the 'Upload' button to upload the files. A CGI-Perl script then takes the data files and save them on their own specific folders. Special Perl codes: binmode(STDIN), binmode(STDOUT), and binmode(STDERR) are needed if the server uses the Windows Operating System.

After the data is uploaded on the server, the simulation can then process the data, plot the contour, and generate the 3D surface based on computational results. To compare the difference using the same algorithm with different parameter values, two generated surfaces are presented in the VRML world and two contours are plotted on the simulation. This is to show that the same algorithm with different parameter values may result in different contour lines and surfaces. The students therefore can understand that the generated contours and surfaces are only computational results and depend on the selection of parameter value of the algorithm. The main features of this simulation are as follows:

1. The main surveying simulation interface contains three areas: button, contour, and message areas.

2. If the user clicks the 'Input' button, a new window appears. The window is used to specify the values of various parameters. The user can change these values, but there are some restrictions on the parameters. The Q values must be less than 3.0 and greater than 1.5 due to numerical restrictions. The number of grids along x, y should be less than 20; otherwise it will take several minutes to finish the calculation.
3. If the user clicks the 'Process' button, the button remains depressed and the simulation becomes inactive, which indicates that the simulation is conducting computation. After the 'Process' button pops up, the simulation becomes active again. If the user does not make any change in the input window, the 'Process' button is inactive since the calculation is completed. However, if the user changes any one of the first three values in the Input window, the 'Process' button is re-activated. If the user only changes the value of the number of contour lines, the 'Process' button remains inactive.
4. After the user clicks the 'Process' button, the Buttons 'Contour 1', 'Contour 2', 'V Compare', and 'V Check' become active. If the user clicks the 'Contour 1' and 'Contour 2' buttons, 2D contours are generated. If the user clicks the 'V Compare' and 'V Check' buttons, the VRML world is updated based on the results of the calculation.
5. If the user clicks the 'Report' button, a report window appears. The actual data is from the validation file (no interpolation) and assumed to be the exact elevation. The computed data is based on the Q parameter in the report window and not the Q parameters used to calculate 2D contours. The user can adjust the value of Q

parameter in the report window to obtain the minimum value of factor by clicking 'Calculate' button.

6. If the user clicks the 'Clear' button, the contours are erased.

The surveying module is a paradigm that demonstrates the power of using various Internet technologies to explain complex engineering concepts. The unique creativity of the module is that it can display 2D contours and 3D surfaces simultaneously over the Internet. The user can also upload a data file to the server and process it using the surveying simulation. Furthermore, the user does not need to maintain the processing tool because it runs on the server.

6.3.4 Foundation

The foundation module was designed for the course of Foundation Engineering at the University of Oklahoma and used in the spring of 2000. In foundation engineering, most bearing capacity theories consider a surface along which the soil is assumed to fail under loading. The assumed failure surface usually does not properly account for such effects as the eccentricity of the load; thus the actual failure surface is usually different from the assumed surface. Also, students taking a course of foundation engineering frequently experience difficulty when trying to understand the stress distribution in soil supporting a foundation. The foundation module was developed to help students better comprehend these concepts.

The information session of the foundation module includes seven subtopics: Introduction, Terzaghi, Modification, General, Eccentricity, Hansen, Meyerhof, and References (Fig. 6.3.9). The Terzaghi subtopic discusses the capacity equations of strip foundation, circular foundation, and square foundation using the Terzaghi's bearing capacity theory. A modified version of these equations is also presented. Terzaghi's theory is applicable only to continuous, square, and circular foundations. To account for this limit, the general bearing capacity equations proposed by Hansen and Meyerhof are explained in the information session.

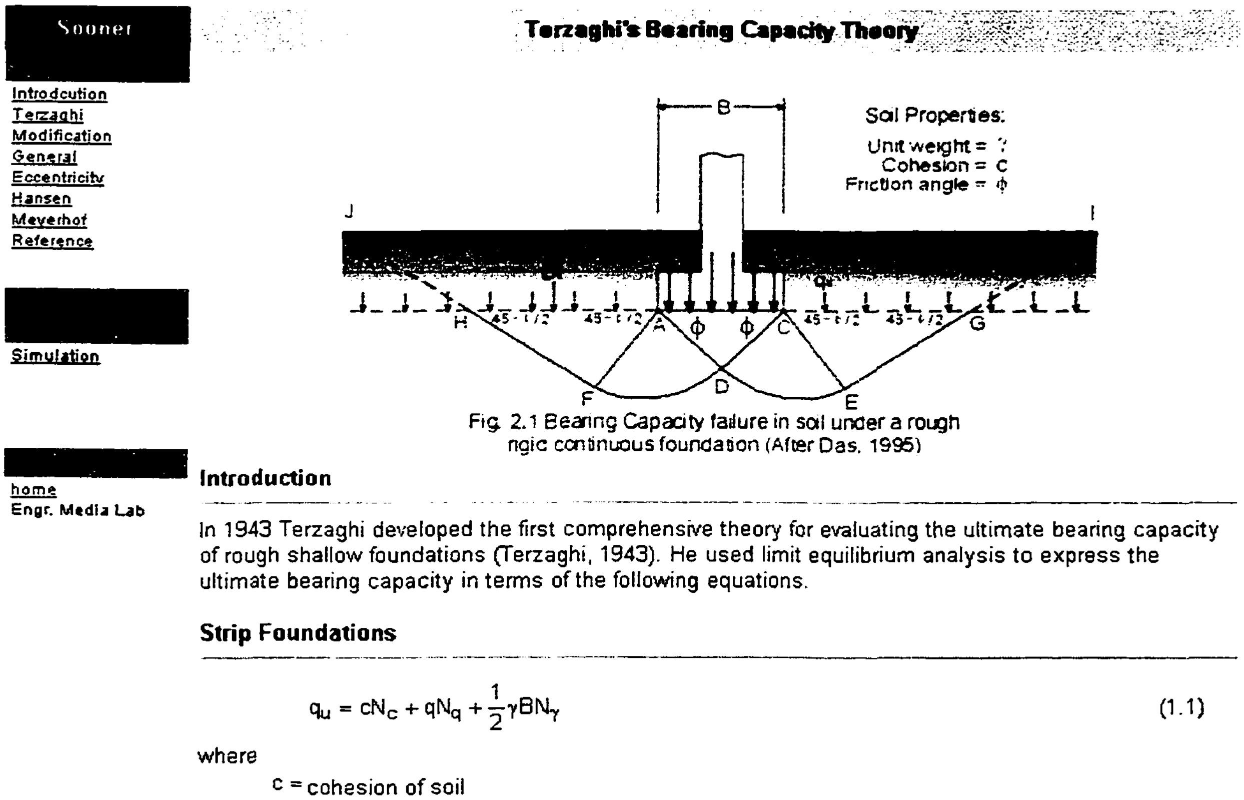


Fig. 2.1 Bearing Capacity failure in soil under a rough rigic continuous foundation (After Das, 1995)

Introduction

In 1943 Terzaghi developed the first comprehensive theory for evaluating the ultimate bearing capacity of rough shallow foundations (Terzaghi, 1943). He used limit equilibrium analysis to express the ultimate bearing capacity in terms of the following equations.

Strip Foundations

$$q_u = cN_c + qN_q + \frac{1}{2}\gamma BN_\gamma \qquad (1.1)$$

where

c = cohesion of soil

Fig. 6.3.9 Information Section of the Foundation Module

The simulation of foundation module can be used to examine the effect of load magnitude, eccentricity, water table, and soil properties on the foundation size. It can also be used to compare the difference of failure predictions based on finite element and the two previously mentioned theories. The distribution of a variety of stresses in soil for an applied load on the foundation can be examined. Also, the concept of bearing capacity failure is illustrated by an animation with a voice explanation. The main features of the foundation simulation are as follows:

1. The Shockwave simulation calculates the width of the foundation based on the Terzaghi's bearing capacity theory or general bearing capacity theory using an iteration strategy.
2. If the 'Input' icon is clicked, the user can specify the values of numerous parameters and select the desired theory. The user can accept the default values.
3. Before the user uses finite element analysis (FEA) method to calculate stresses, the user must first mesh the computation area by clicking the 'Mesh' icon, which is the third icon. By moving slider bars, the user can change the number of elements.
4. After the user select the desired number of elements, the user can then click on the 'Matrix' icon to perform FEA. The finer meshing the user chooses to use, the more time it will take to finish the FEA process. For example, it takes about 90 seconds in a 400MHz computer to complete a FEA process with 8×6 meshing.
5. After the FEA calculation is over, the user can then view the stress components, such as x stress, y stress, shear stress, minimum principle stress, maximum principle stress, and shear principle stress.
6. By clicking the sixth icon, the user can view an animation, which demonstrates the behavior of the footing when applied to loading.

Figure 6.3.10 is a possible distribution of x stress obtained by the foundation simulation. The grid shows how the computed area is meshed. The red contour lines demonstrate the area whose maximum principal stress is larger than 7.819 psi. Other contour lines' color changes gradually from red to green. The number of total elements in this example is 192. More elements usually mean better results. However, it takes more time to obtain the results, because finite element analysis is computation-intensive.

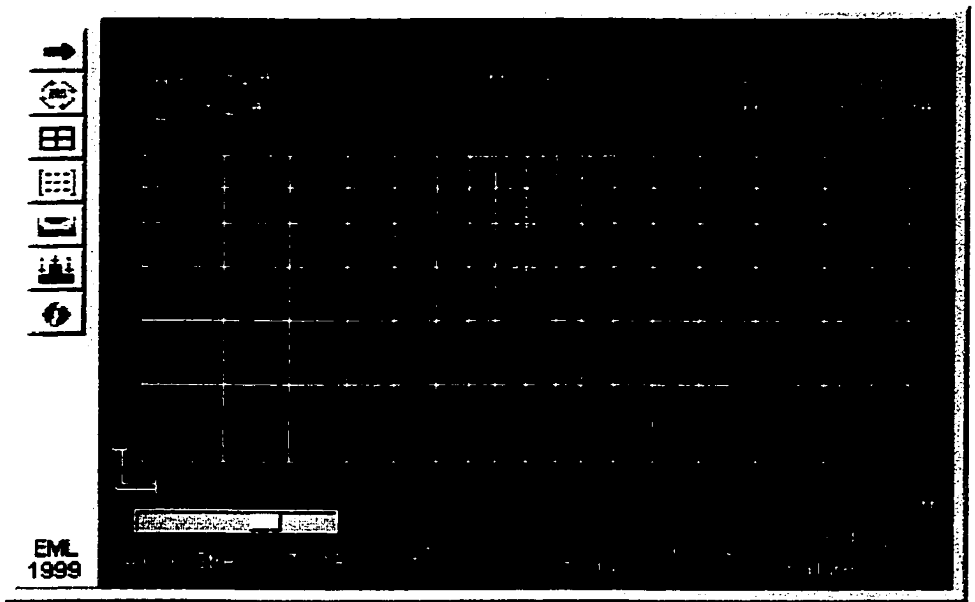


Fig. 6.3.10 X Stress Distribution in the Foundation Simulation

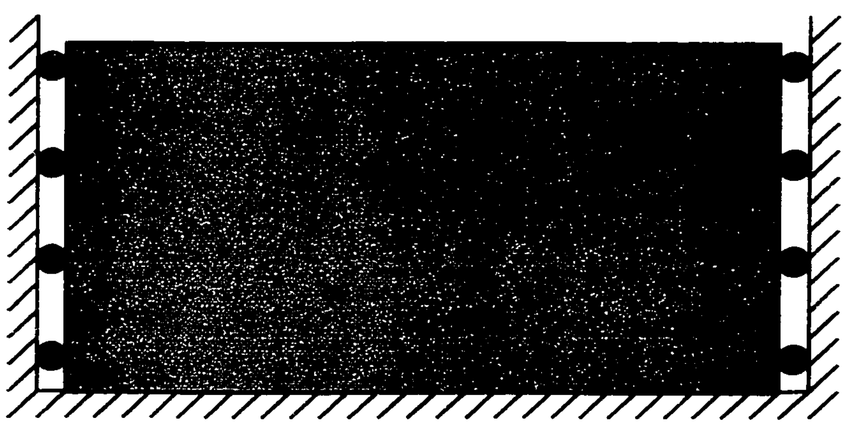


Fig. 6.3.11 Boundary Conditions of the Foundation Simulation

The soil under the foundation is assumed to be a plain strain problem, because the foundation in z direction is significantly long. Triangular elements are used due to its ease of programming. The mesh strategy is simple; the area near to the foundation has more elements (Fig 6.3.10). The boundary conditions are illustrated in Fig. 6.3.11. The left and right side are rollers while the bottom side is fixed.

The foundation simulation was found to be the first Shockwave simulation to implement finite element analysis visually over the Internet, which is a unique feature of the foundation module. The interface is user-friendly because the user does not need to prepare the data using other programs. The user can perform automatic meshing by moving a slider bar. This tremendously reduces the tedious work of data preparation such as the numbering of nodes. The contour algorithm of the surveying module was used in this simulation to draw the colored stress lines. The stress distribution is hence visually demonstrated using these colored lines. Because of this, the area with high stresses and low stresses can be easily located.

6.3.5 Soil

The soil mechanics module was designed for the Soil Mechanics course at the University of Oklahoma. In the foundation module, the distribution of stresses under the foundation is examined based on the finite element method while in this module the net increase of vertical stress in soil is estimated based on elasticity theory. The best way to understand the net increase of vertical stress due to a point load, line load, and string load is to demonstrate their distribution visually in the soil. Thus, one of the main purposes of this module was to show the distribution of the net increase of vertical stress visually under one or multiple loads. Another purpose was to present a curve of the lateral pressure on the retaining wall when multiple loads are applied.

Sooner

Stress Caused by Point Load

Introduction
Point Load
Line Load
String Load
Increasing Load
Lateral Pressure

Simulation

home
Engr. Media Lab

Boussinesq's Solution

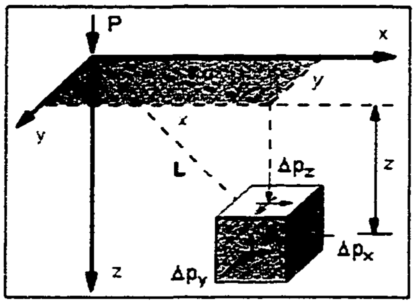


Fig. 3 Stresses due to point load

In 1883, Boussinesq solved the problem of stresses produced at any point in an isotropic, homogeneous and elastic material when a point load is applied on the surface (Fig. 3). The normal stresses at point A due to the point load P are:

$$\Delta p_x = \frac{P}{2\pi}\left\{\frac{3x^2}{L^5} - (1-2\mu)\left[\frac{x^2-y^2}{Lr^2(L+z)} + \frac{y^2 z}{L^3 r^2}\right]\right\} \quad (2.1a)$$

$$\Delta p_y = \frac{P}{2\pi}\left\{\frac{3y^2}{L^5} - (1-2\mu)\left[\frac{x^2-y^2}{Lr^2(L+z)} + \frac{y^2 z}{L^3 r^2}\right]\right\} \quad (2.1b)$$

$$\Delta p_z = \frac{3P}{2\pi}\frac{z^3}{\left(r^2+z^2\right)^{5/2}} \quad (2.1c)$$

Where

$r = \sqrt{x^2+y^2}$

$L = \sqrt{x^2+y^2+z^2}$

μ = Poisson's ratio

Fig. 6.3.12 Information Section of the Soil Module

The information section of the soil module covers five subtopics: Point Load, Line Load, String Load, Linearly Increasing Load, and Lateral Pressure on the Retaining Wall (Fig. 6.3.12). Under the assumption that soil is elastic, isotropic and homogeneous, theoretical solutions of net increase of vertical stress are presented. Based on results of net increase of vertical stress, theoretical solution of lateral pressure on the retaining wall is also explained.

The simulation of the soil module performs the computation based on the theoretical equations. Two topics of soil mechanics are covered in this simulation. The first one covers the vertical stress distribution under various loads. For example, when a line load of infinite length with an intensity q/unit length is applied on the surface of a semi-infinite soil mass, the net increase of vertical stress at point A (Fig. 6.3.13) can be determined by the following equation:

$$\Delta p_z = \frac{2qz^3}{\pi\left(x^2 + z^2\right)^2} \tag{6.3.1}$$

Note that the value calculated by Eq. (6.3.1) is the additional stress on soil due to the line load, which does not include the overburden pressure of the soil above the point A. Vertical stress increment distribution under two types of loads is illustrated by contour lines (Fig. 6.3.14).

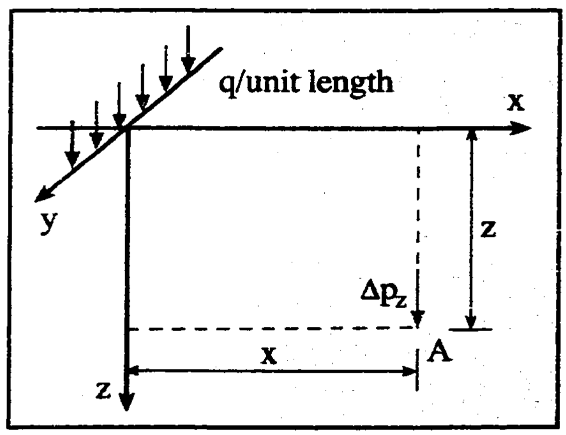


Fig. 6.3.13 Line Load over the Surface of a Semi-infinite Soil Mass

The second topic covers the lateral pressure due to different loads. A curve is presented to show the lateral pressure on the retaining wall (Fig. 6.3.15). The point load, line load, strip load, and embankment load are applied at the top of the soil. The superposition method was used to determine the vertical stress net increment at any point under multiple loads.

The main features of the simulation are as follows:

1. For the point load and line load, the maximum vertical stresses are assumed to be equal to the point load and the line load. Theoretically, the maximum vertical stresses under the point load and line load are infinity.

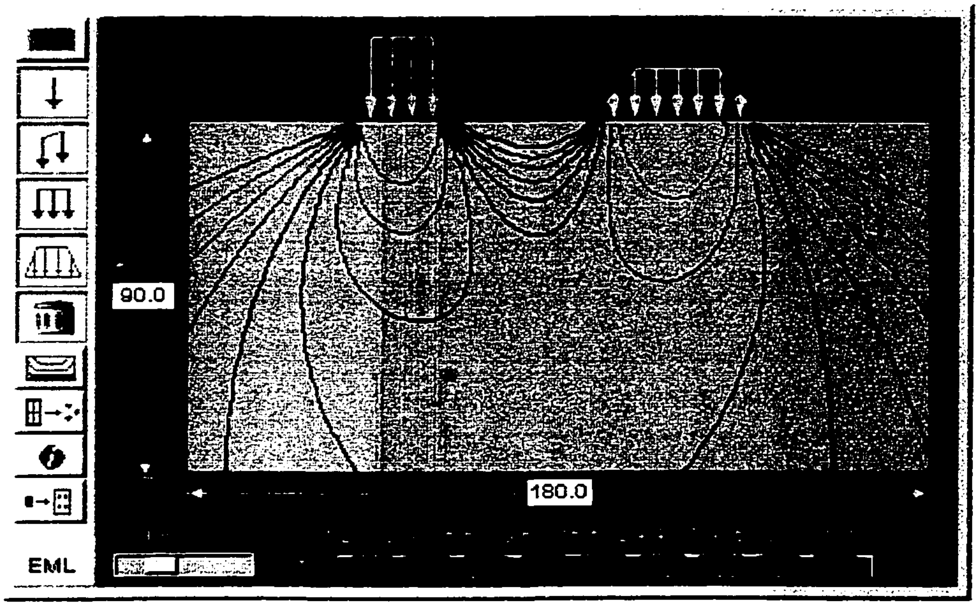


Fig. 6.3.14 Distribution of Net Increase of Vertical Stress under Multiple Loads

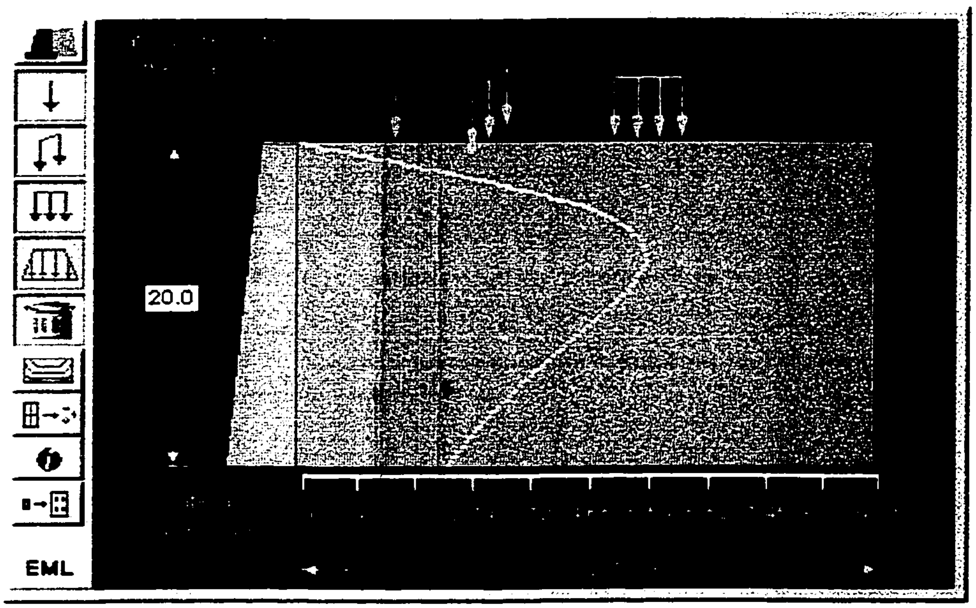


Fig. 6.3.15 The Curve of Lateral Pressure on the Retaining Wall under Loads

2. The point load, line load, strip load, and embankment load are moved horizontally with a "click-and-drag" motion.
3. The values of these loads can be changed with a "click-and-drag-the-heads-of-the-loads" motion.
4. Load magnitude can be modified by doubly clicking on the load.
5. The maximum numbers of point loads and line loads are five. The maximum number of strip loads is three. Only one embankment load is allowed.
6. The unit can be ft and lb or N and m.
7. The individual load can be cleared by "click-and-drag" to the 'Trash' icon.
8. All of the loads are deleted if clicking on the 'Clear' button.
9. Moving the slider can change the scale of the contour line's values.
10. If the user clicks on the 'Submit' button, a new window pops up to ask the user to set the dimensions of an earth dam. This earth dam is deposited in the Virtual City if the 'OK' button is clicked (Fig. 6.3.16). The dam was chosen because it produces an embankment load.

This simulation is an excellent illustration to demonstrate the superposition method. The user can add, delete, or move the forces to experience the different combined effects using the contour lines. The simulation is therefore straightforward and intuitive. Because the theoretical equations are used, the results are obtained quickly. Hence, the user can compare this simulation with the foundation simulation, which employs finite element method. Also, visualization of net increase of vertical stress can help users better understand the theoretical equations.

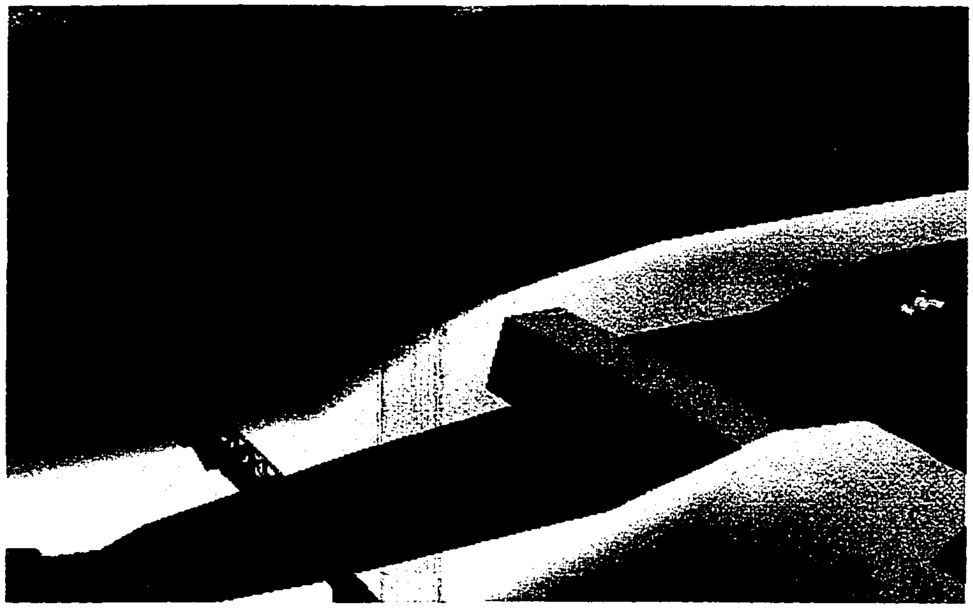
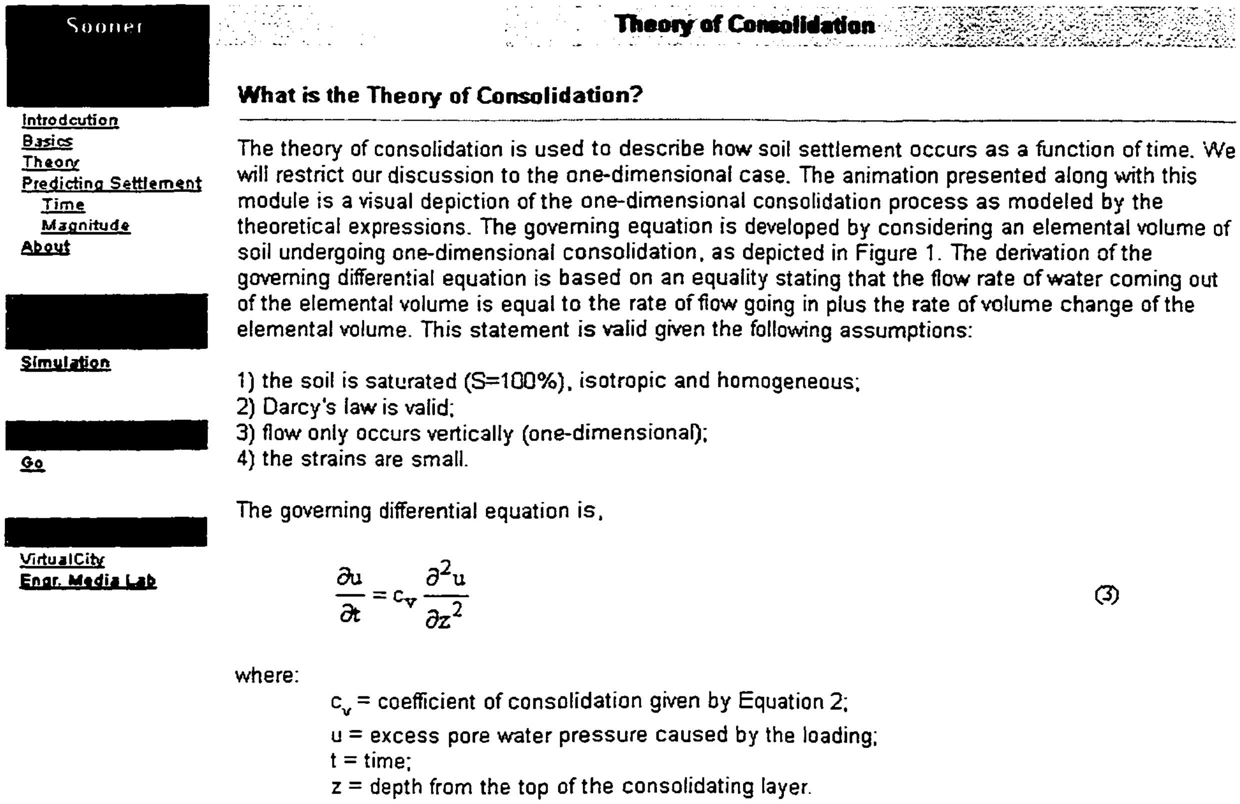


Fig. 6.3.16 The Dam Created By the Soil Simulation

6.3.6 Consolidation

The consolidation module is the second module designed for the course of Soil Mechanics at the University of Oklahoma, which can be used to reinforce the knowledge of the consolidation process in saturated soils. Its main purpose was to simulate how pore water pressure, effective stress, and settlement evolve over time, in an effort to help students that usually experience difficulty in comprehending the relationships between these parameters.

The information section presents an overview of the main principles and aspects of the theory of consolidation (Fig. 6.3.17). Only the essential elements are addressed, because the overview is not intended to give details on every aspect of the theory. Four subtopics were covered, including Introduction, Basics of Consolidation, Theory of Consolidation, and Settlement Prediction in Terms of Time and Magnitude.


Sooner

Introdcution
Basics
Theory
Predicting Settlement
Time
Magnitude
About

Simulation

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VirtualCity
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Theory of Consolidation

What is the Theory of Consolidation?

The theory of consolidation is used to describe how soil settlement occurs as a function of time. We will restrict our discussion to the one-dimensional case. The animation presented along with this module is a visual depiction of the one-dimensional consolidation process as modeled by the theoretical expressions. The governing equation is developed by considering an elemental volume of soil undergoing one-dimensional consolidation, as depicted in Figure 1. The derivation of the governing differential equation is based on an equality stating that the flow rate of water coming out of the elemental volume is equal to the rate of flow going in plus the rate of volume change of the elemental volume. This statement is valid given the following assumptions:

1) the soil is saturated (S=100%), isotropic and homogeneous;
2) Darcy's law is valid;
3) flow only occurs vertically (one-dimensional);
4) the strains are small.

The governing differential equation is,

$$\frac{\partial u}{\partial t} = c_v \frac{\partial^2 u}{\partial z^2} \qquad (3)$$

where:

c_v = coefficient of consolidation given by Equation 2;
u = excess pore water pressure caused by the loading;
t = time;
z = depth from the top of the consolidating layer.

Fig. 6.3.17 Information Section of the Consolidation Module

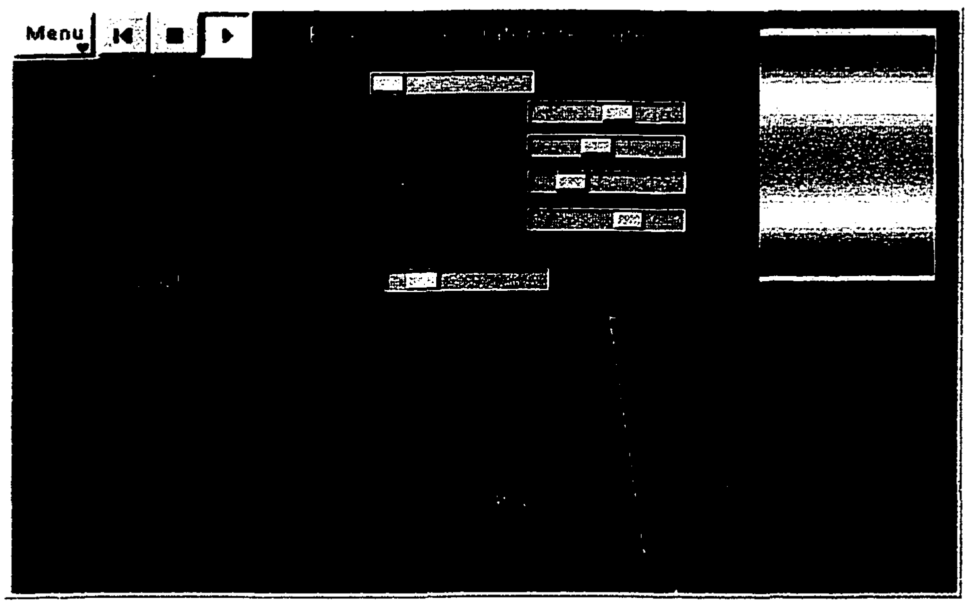


Fig. 6.3.18 Consolidation Simulation

The simulation is an animation to demonstrate time-based consolidation concepts. The user can see the effect of modifying consolidation parameters for a soil layer subject to one-dimensional loading (Fig. 6.3.18). Three time-based processes are simulated. They are the change of pore water pressure with time, effective stress with time, and settlement with time. Colors and curves are used to represent time-based values of pore water pressure and effective stress. The user can experiment with these parameters to see the effect. To demonstrate the details of the processes, the values at five locations - A, B, C, D, and E - are represented in curves in terms of time. The main functions of the simulation are as follows:

1. The user can start the simulation by clicking the 'Menu' button.
2. There are six menu items available in the menu window, which are 'Introduction', 'Pore Water Pressure', 'Effective Stress', 'Settlement', 'Submit', and 'About'.
3. If the 'Introduction' is clicked, the user can select "Permeable" or "Impermeable" for one layer.
4. The values of the parameters can be changed by moving the sliders. For example, if the user moves the speed slider, the consolidation is simulated in the modified rate.
5. When the process is finished, the values at each step can be obtained by rolling the mouse over the curves. This is particularly convenient when the user wants to read the values at a specific time.
6. If the user clicks 'Submit' in menu window, the user is able to modify the geometric dimensions of the landfill in the virtual world.

The consolidation process is usually slow and may extend to years. Using this simulation, the user can speed up and slow down the process by changing the value of the time parameter and then see the details of the process. This is a unique and powerful feature of the simulation. The user can also modify consolidating parameters to experience the time-based changes of the excess pore water pressure, vertical effective stress, and consolidation settlement. These changes are visualized using various colors and animated graphics.

6.3.7 Structural Analysis

The structural analysis module was designed for the Structural Analysis course at the University of Oklahoma. Its main purpose was to provide a generic solver for plane truss and frame problems. It is important for a structural designer to know how to compute the forces and displacements of truss structures and how to compute the deflections, moments, shears and axial forces of frame structures. Although a complex commercial finite element code could be used to check the results, it is usually not readily available and generally finite element codes have a steep learning curve. Thus it is particularly useful to provide a convenient solver that can be used to check the computation results of trusses and frames. Furthermore, the user can learn the concepts of structural analysis by designing and solving structures using the solver.

The structural analysis module contains two sections: an information section (Fig. 6.3.19), and a simulation section (Fig. 6.3.20). The information section covers basic concepts for four topic areas that include trusses, frames, stability, and the stiffness method. This section is to give the student background information about trusses and frames so that they can better utilize the simulation.

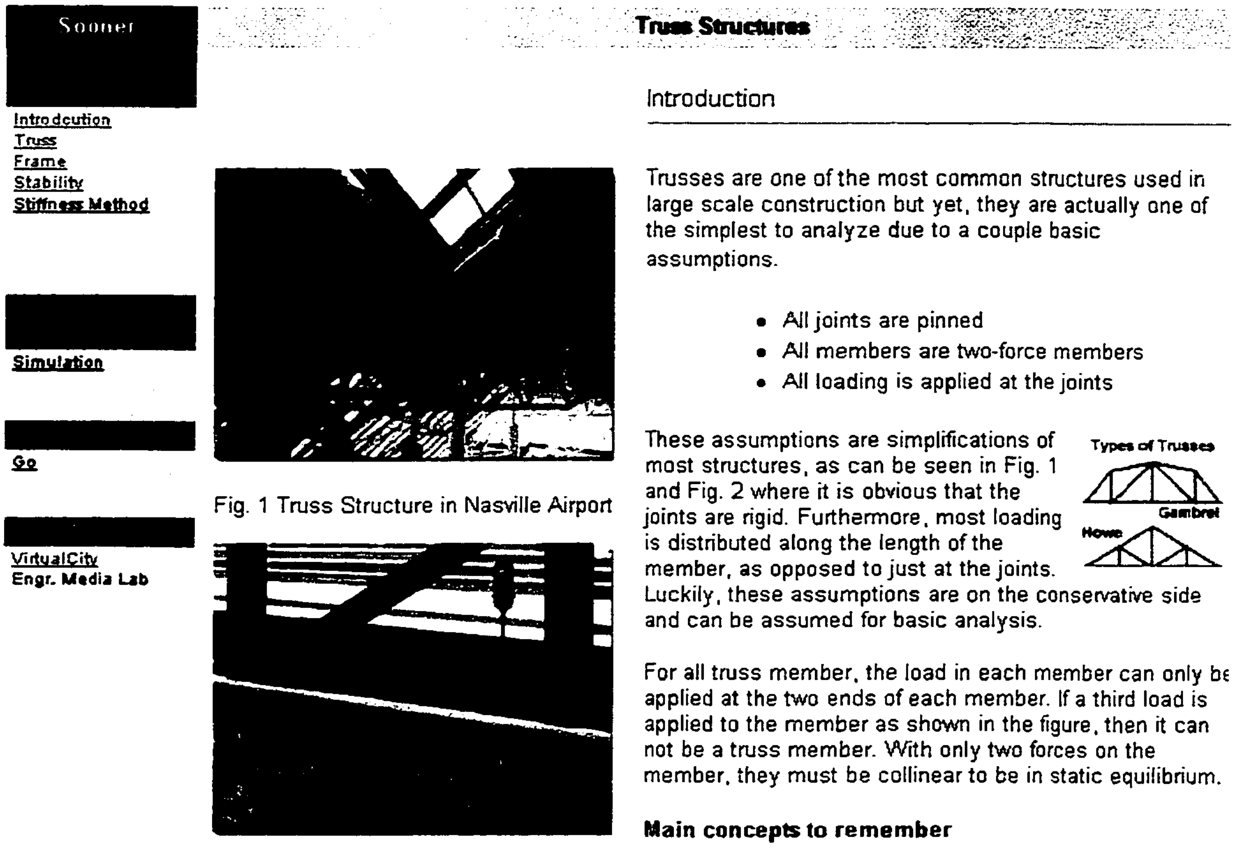


Fig. 6.3.19 Information Section of the Structural Analysis Module

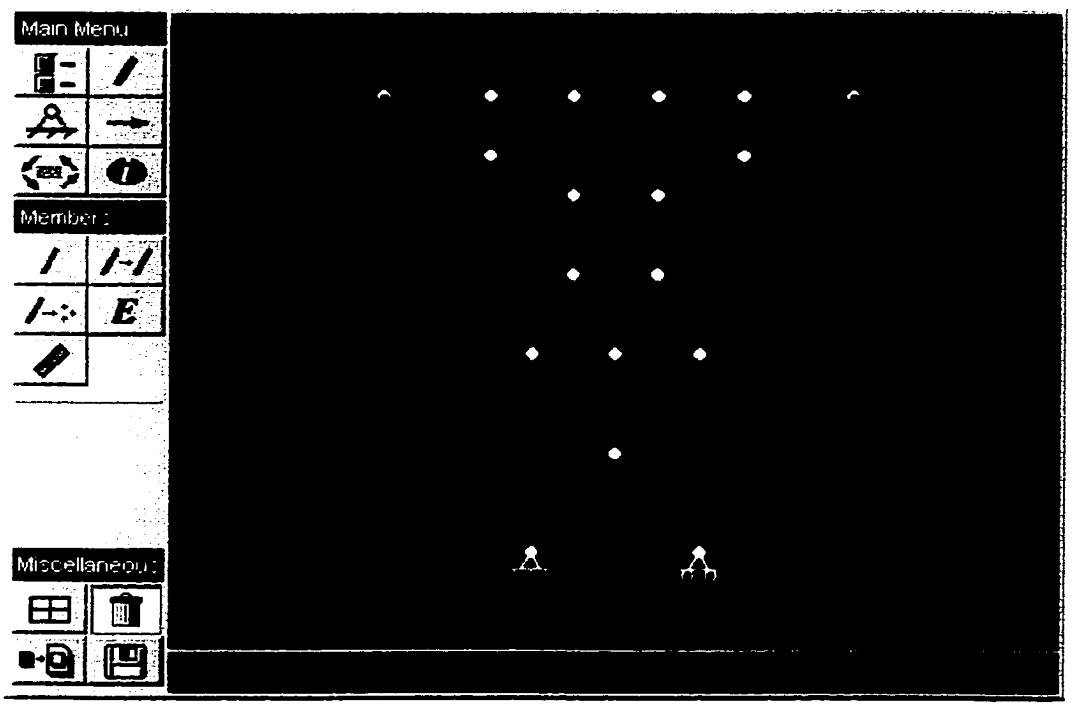


Fig. 6.3.20 Structural Analysis Simulation

The second section is the actual simulation that includes a help page. The simulation was programmed using Macromedia's Director that can be saved as an Internet-based Shockwave file. The actual scripting or programming language in Director that was used is called Lingo. The simulation is basically a finite element method (FEM) solver for trusses and frames. Although it is easy to obtain the code of the computational procedures of FEM, programming FEM in Lingo was challenging since it is actually a scripting language that is not suited for matrix operations.

In addition to the actual FEM solver, the other main challenge to programming the simulation was the graphical input and output. It was important to design the interface so that any engineering student could easily understand how to operate the program without the need of a reference manual or keeping track of node and element numbers. The purpose of the simulation was to help the student understand trusses and frames, and not FEM. Also, to minimize file size, all input and result graphics were based on vectors and not pixel-based graphics. Vector-based graphics can be completely controlled by Lingo, therefore it is particularly efficient to create, move, and delete the graphics dynamically. Using vector-based graphics minimizes the simulation's file size to about the size of a large graphic file.

Basically, two types of structures can be solved using this simulation – truss structures and frame structures. For truss structures, the user can draw any kind of valid truss structure, apply boundary conditions such as pinned joints and roller joints, and specify the forces to any node of the truss. Because each truss member is considered internally as an element, the user can draw only one member at a time. Only point forces can be applied to the node. The maximum number of total members is 85. The maximum number of joints is 13 for each type of joint. The maximum number of forces is 20 for each type of force. The simulation therefore cannot be used to solve large truss problems.

There are two ways to specify detailed input information: the preference window and the member property window. Figure 6.3.21 illustrates the preference window of the simulation. In the preference window, the user can specify appropriate grid step ratio of the grid system to map real-world dimensions. The lengths of the members are determined implicitly based on the grid system. Default values for material and member geometric properties are also set in the preference window. The user can also give material and geometric properties to individual members (Fig. 6.3.22) by double clicking individual members.

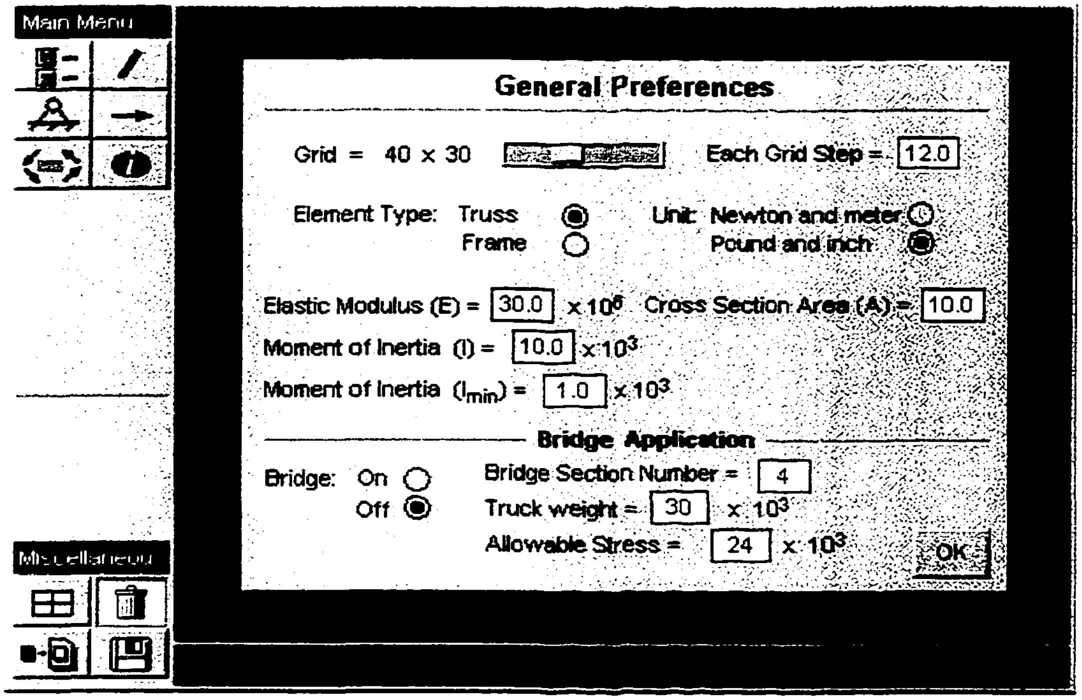


Fig. 6.3.21 Preference Window

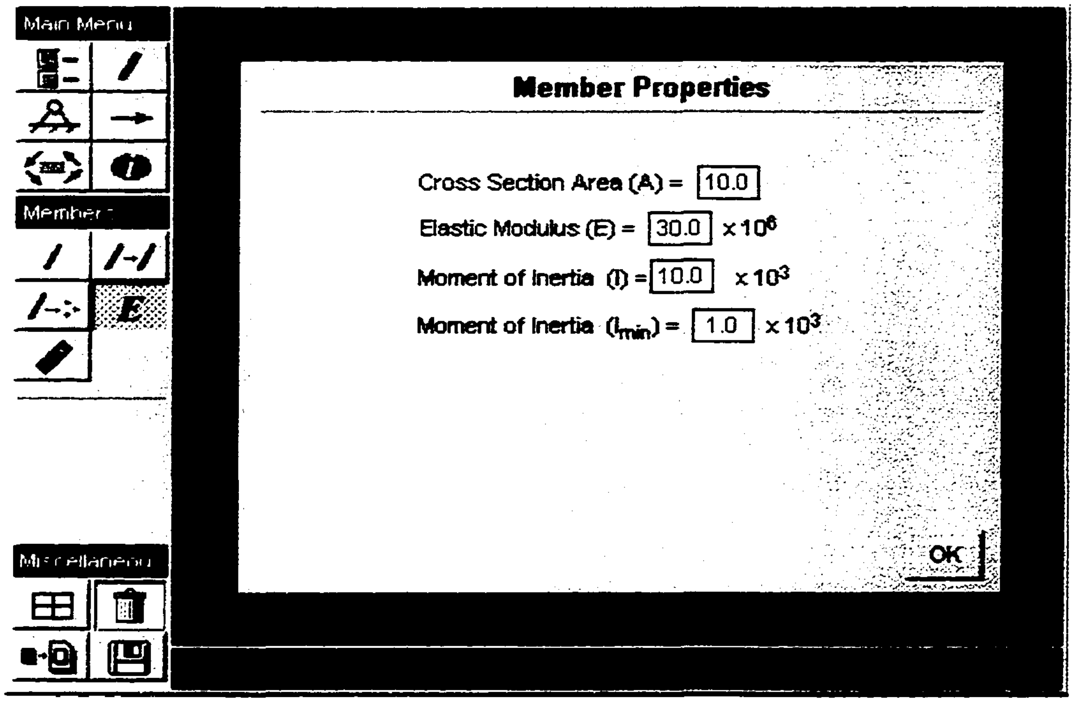


Fig. 6.3.22 Member Property Window

The results for truss structures are presented in four ways: summary of results, report of individual members, displacement visualization (Fig. 6.3.23), and load visualization (Fig. 6.3.24). In the summary of results, the values of the maximum displacement and maximum stress are reported. If an individual member is double-clicked, its displacements and stress can be accessed. Also, the stability of each member is checked and reported based on the basic Euler equation. To demonstrate the relative difference of the displacement, a new truss structure with node movement based on the displacements is drawn. The color is utilized to show the loads in each member.

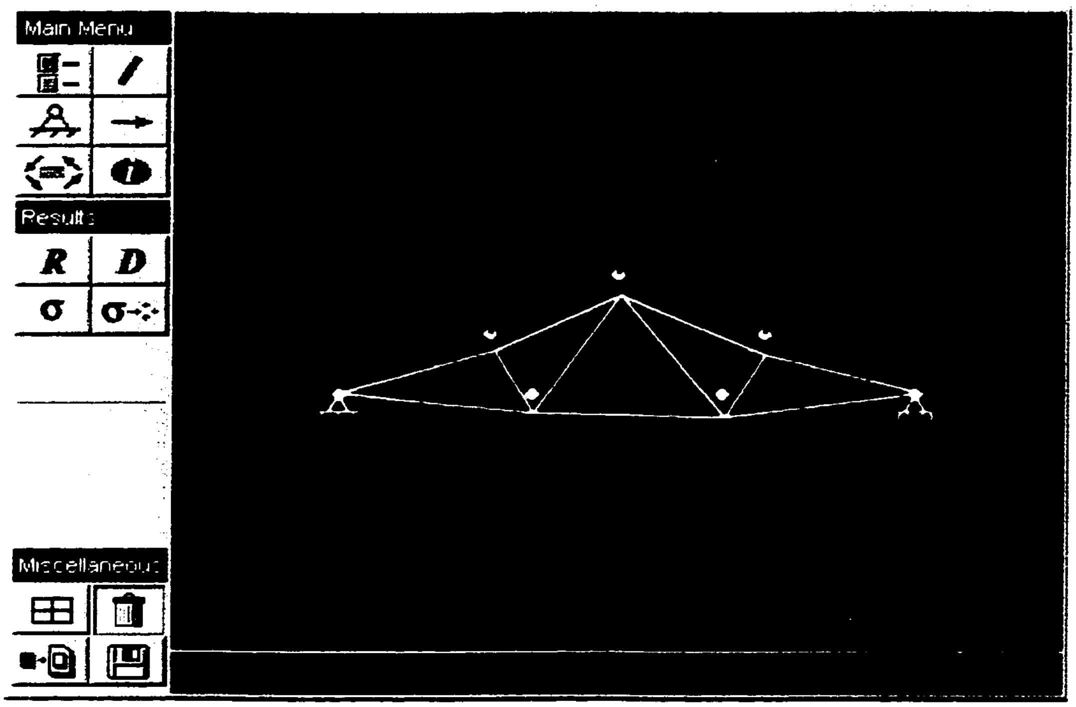


Fig. 6.3.23 Node Displacements of a Truss Structure

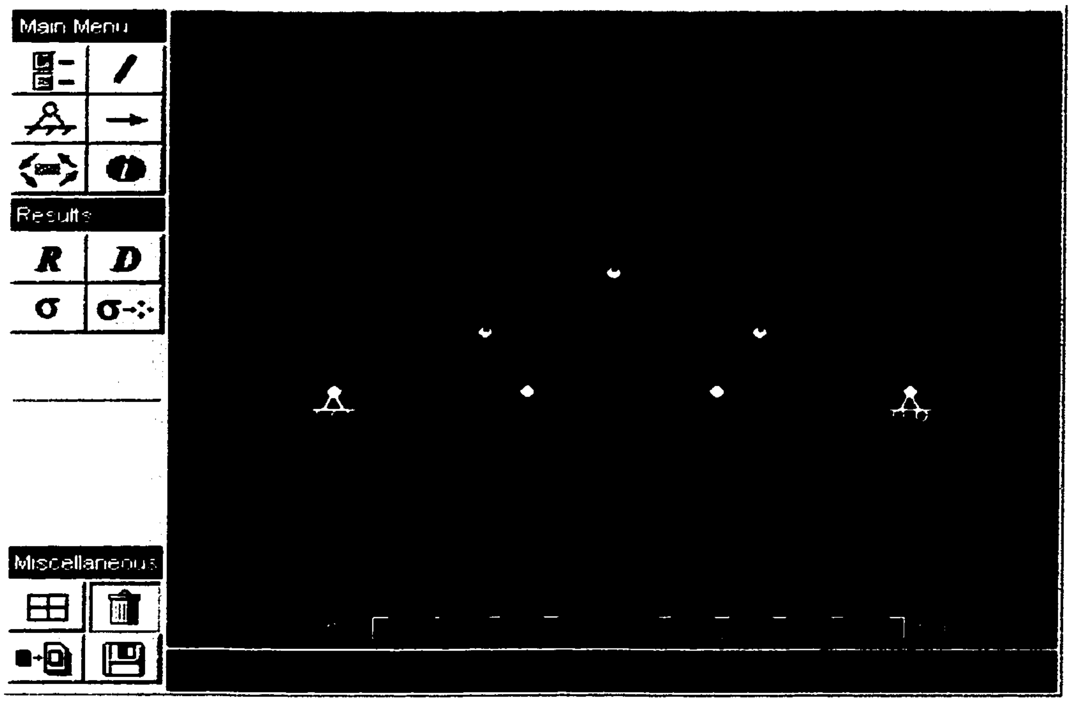


Fig. 6.3.24 Member Loads of a Truss Structure

In addition to truss structures, the user can draw any type of frame structure. The number of members, joints, and forces are limited, similar to the truss structures. Point forces, moment, and distributed loads in x direction and y direction can be applied to the frame. By double-clicking the forces, the user can change their magnitudes. Similarly, the simulation reports a summary of the computational results, such as maximum displacement of nodes, maximum moment of nodes, and maximum axial force of members. Each member's deflection (Fig. 6.3.25), moment diagram (Fig. 6.3.26), shear diagram, axial force diagram can be visually presented.

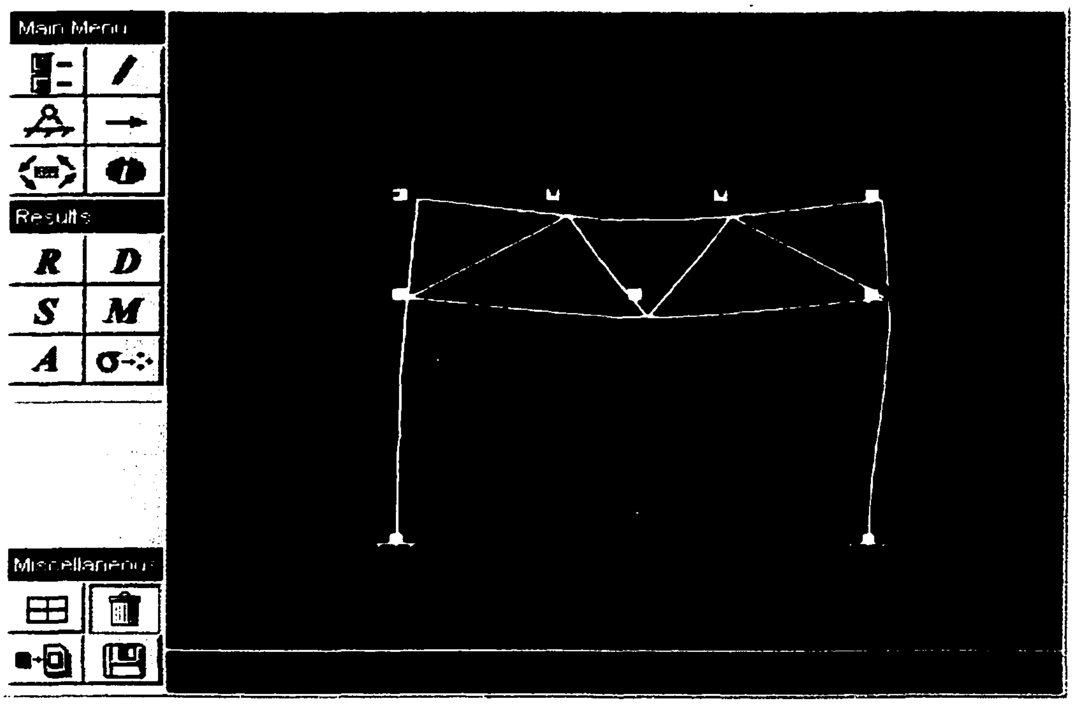


Fig. 6.3.25 Deflection of Members for a Frame Structure

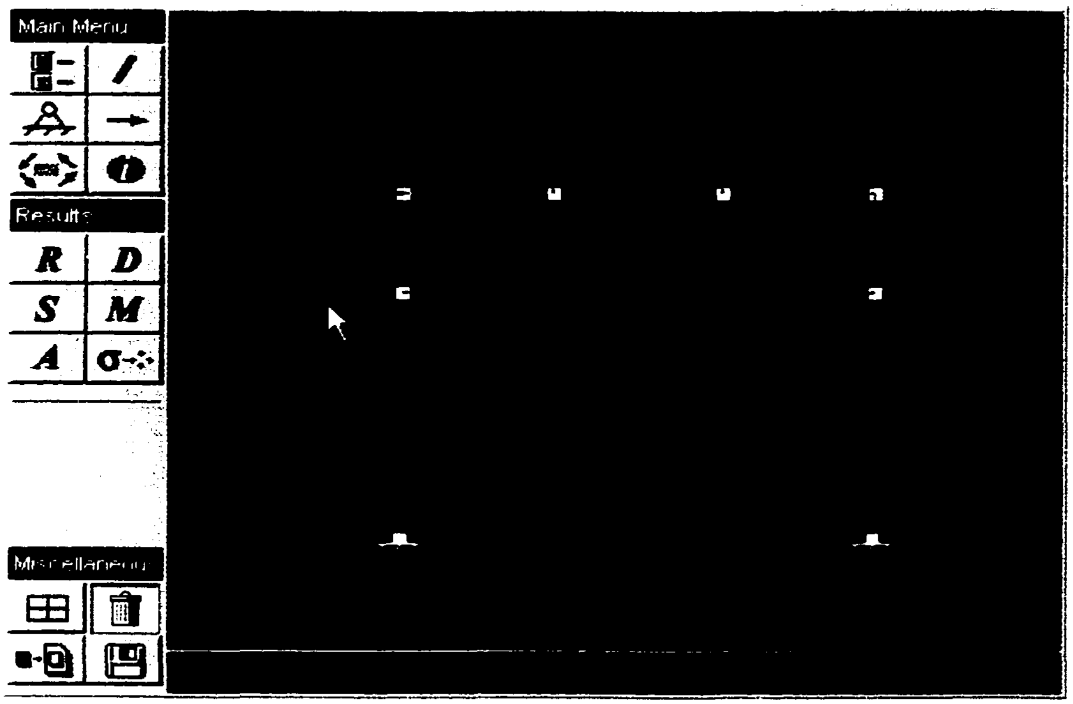


Fig. 6.3.26 Moment Diagram of Members for a Frame Structure

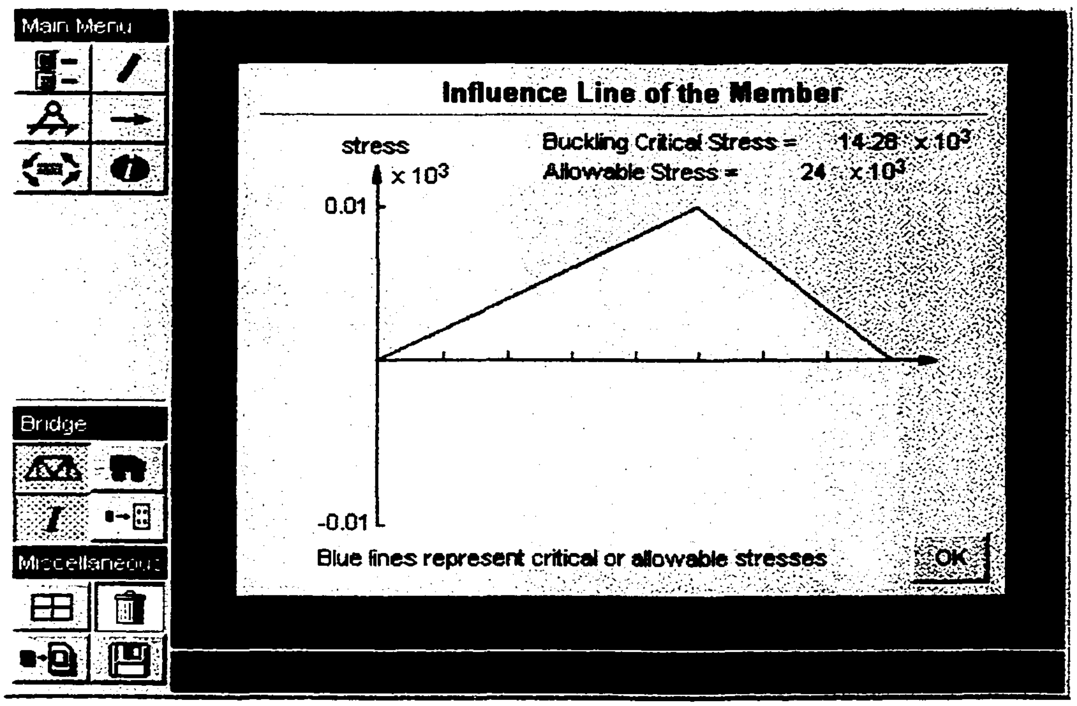


Fig. 6.3.27 Influence Line of the Bridge Member

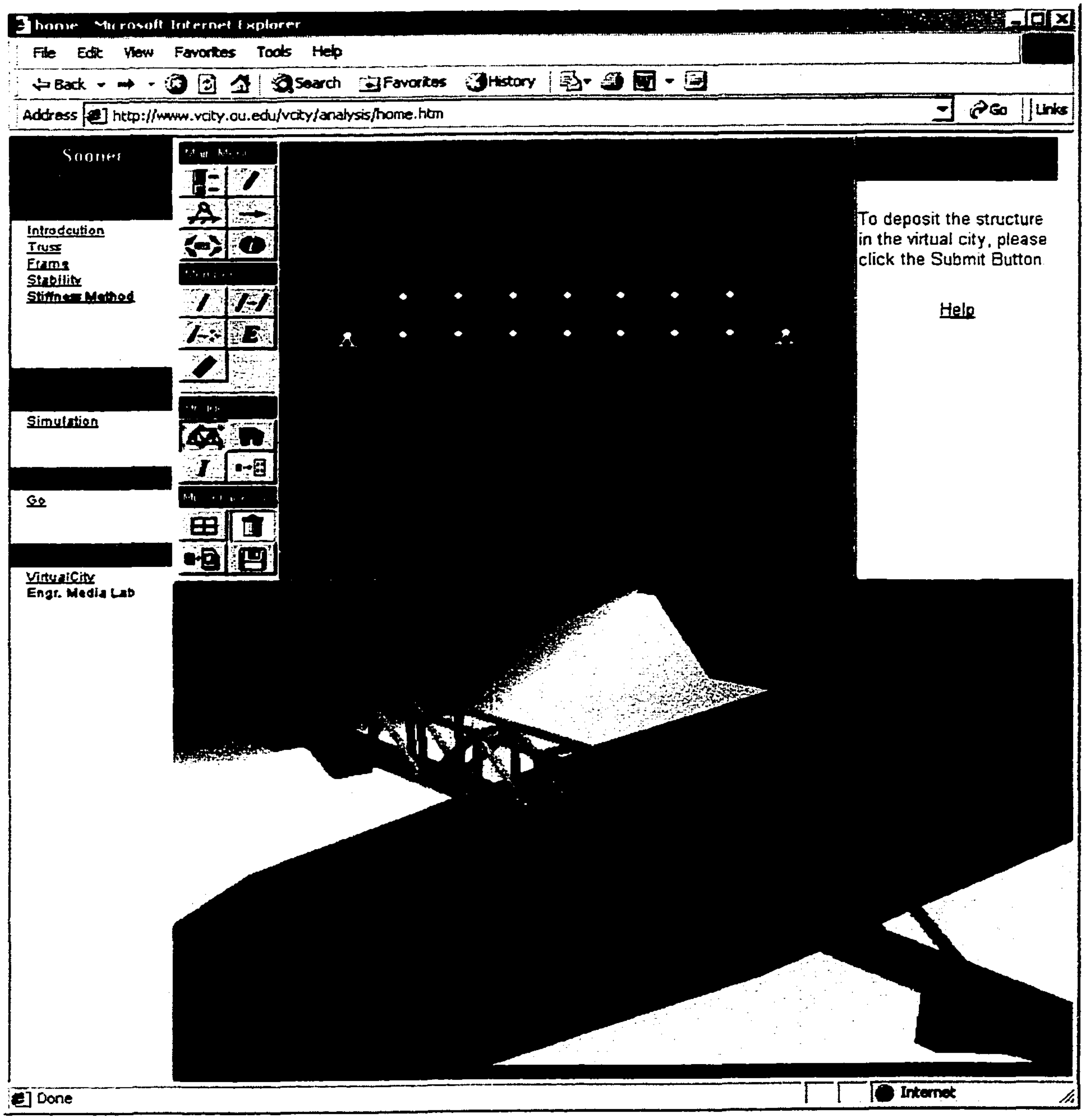


Fig. 6.3.28 Bridge Application of the Simulation

The structural simulation is a generic application, and can be used to help develop various specific applications. One particular application, a bridge with a moving load, was a specific case that was programmed into the simulation due to its unique output needs. After the user chooses the bridge option, the number of the sections in the preference window can be specified. Then the user needs to add the actual truss members between the two end points of the bridge. A moving load, which simulates a vehicle, is applied to the bridge and the program calculates and records the member loads as the vehicle moves across the bridge. From this information, an influence line is drawn for any selected member (Fig. 6.3.27). In addition, an animation is developed to show the displacements of each node when the vehicle is moving. A 3D virtual world, which is an Internet-based city built by the use of various multimedia modules, is used to provide a 'big picture' of the bridge (Fig. 6.3.28). The user can draw a 2D bridge in the simulation and then generate a 3D bridge by depositing it in the virtual world.

The main features of the simulation are as follows:

1. A grid is used to map the real-world dimension through the use of a grip step ratio. By depressing the 'Grid' button, the user can turn the grid on.
2. The steps to use this generic solver are: (1) Click 'Preference' button to set the preference; (2) Click 'Member' button to generate, move, and delete members; (3) Click the 'B.C.' button to apply the boundary conditions such as pin joint and fixed joint; (4) Click 'Force' button to apply forces; (5) Click 'Solve' button to solve the problem; (6) Under the 'Solve' button, click the any sub-button to obtain the information of the results, such as stress of truss member and deflection of the frame member.
3. If the user clicks the 'Trash' icon, all of members, forces, and boundary conditions are deleted.
4. If the user drags a member, joint, or force to the 'Trash' icon, that member, joint, or force is deleted immediately.

5. The property input window can be accessed through double-clicking a member or force.
6. The computation is performed if the user clicks the 'Solve' button.
7. If the user selects to perform truss analysis only a subset of menus of boundary conditions, forces, and results show up.
8. The user can save a structure with boundary conditions and forces on the server. Later, the structure can be retrieved using the simulation. Because only one structure can be saved, the previous structure will be overwritten if the user tries to save another structure. The computational results are not saved, because they can be easily obtained by running the simulation again.

Numerous unique features can be found in this simulation. First, no similar Internet-based frame solver was found during module development. Second, the user can define the truss and frame structures by drawing connected individual members, which is an intuitive and convenient approach. Third, the computational results are visually demonstrated. For truss structures, new truss structures are drawn to display the displacement at each node. For frame structures, new deflected frame structures are generated to represent the deflection of each member, which is usually difficult to draw by hand. Moment and shear diagrams are also drawn for the frame structure, which are simple in concept but tedious to draw them. Fourth, a complex bridge can be designed using this simulation and then deposited into the virtual world. Fifth, the structure as well as the forces and boundary conditions can be saved on the server and retrieved using the simulation. Last, the simulation can help students design simple truss and frame structures with analytical results.

6.3.8 Concrete

The concrete module was designed for the Concrete Design course at the University of Oklahoma. Its main purpose was to compare the results of the working stress method and strength design method. The working stress method was the dominant concrete design method in United States before 1970's, and it was gradually replaced by the strength design method since then. This is because the strength design method has numerous advantages over the working-stress method. For example, the strength design method better estimates load-carrying ability, uses a more consistent theory, employs a more realistic factor of safety, and permits more flexible designs. However, using both methods on the same beam and comparing their results can deepen the students' understanding of these two methods.

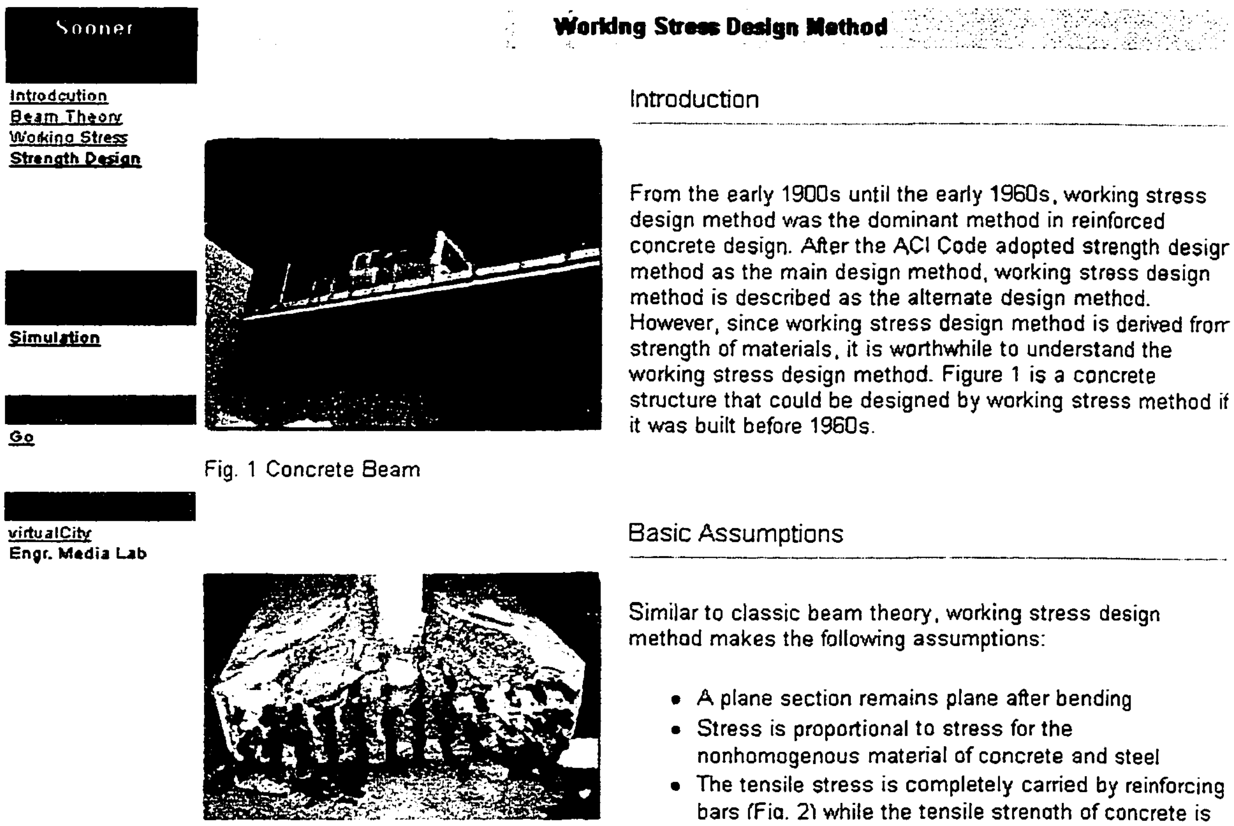


Fig. 6.3.29 Information Section of the Concrete Module

The information section of the concrete module discussed four subtopics: Introduction, Beam Theory, Working Stress Method, and Strength Design Method (Fig. 6.3.29). The classic beam theory was reviewed, because it is the foundation of the working stress method. The theory of working stress method and the strength design method was covered using text, equations, and illustrations. The user can grasp the basic differences of the two methods by studying the information section.

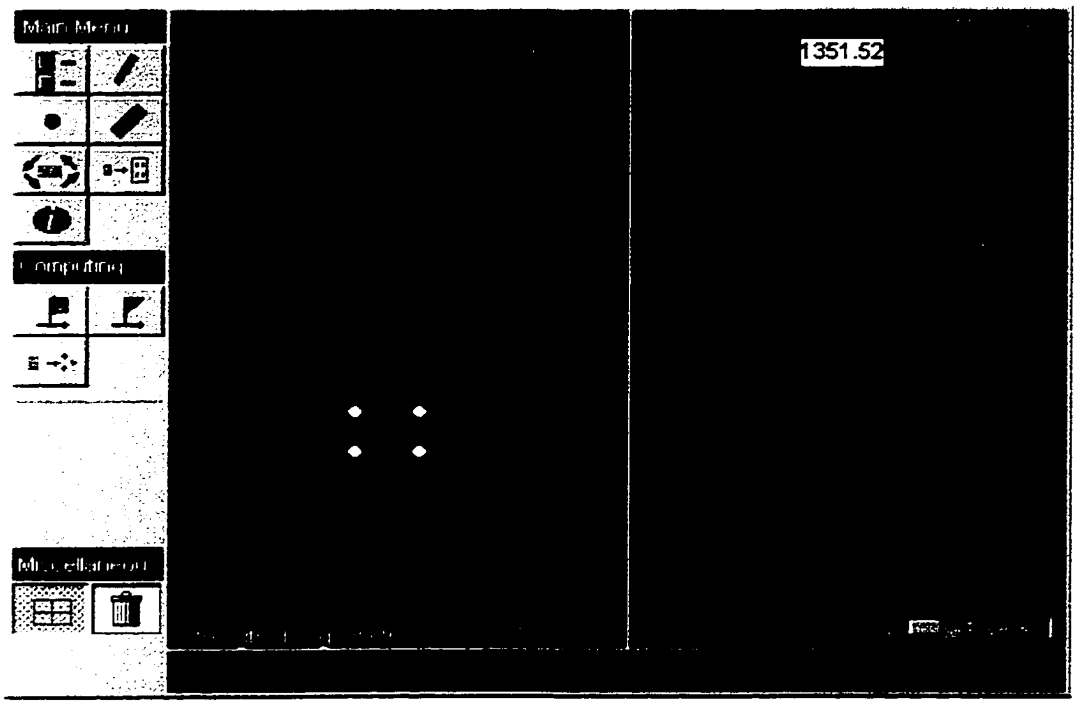


Fig. 6.3.30 Concrete Simulation

The concrete simulation is a generic tool for comparing both methods (Fig. 6.3.30). The main functions of the simulation are as follows:

1. The user can set preferences such as concrete maximum compression stress, reinforcing bar yield stress, and grid parameters. The grid parameters are used to define the real-world dimensions of the geometry.
2. By manipulating individual members, the user can draw beam cross sections, such as rectangular and triangular shapes. The members can be generated and deleted by "Click-and-Drag" motion. Dimensions of the cross section can be adjusted by moving the end of the members.
3. Reinforcing bars can be applied, moved, and deleted. The positions of the bars relative to the cross section are computed automatically in the simulation.
4. The user can then compute the permissible ultimate moment capacity of the concrete beam and the position of the neutral axis using the strength design method. Under this same moment, the stress distribution can be obtained using the working stress method.
5. The computational stresses from the working stress method can be compared with the concrete maximum compression stress and reinforcing bar yield stress. The strength design method uses the computational stresses to calculate the moment.
6. The geometric shape can be deleted, and new ones can be built.

To link the concrete module to the virtual world, an overpass on the highway can be built using the simulation (Fig. 6.3.31). The cross section of the beam in the virtual world is generated from the concrete drawn by the user. The number of the beams can be specified to let the user design a reasonable overpass. The beams are below the road, but the user can adjust the transparency of the road to make the beams visible.

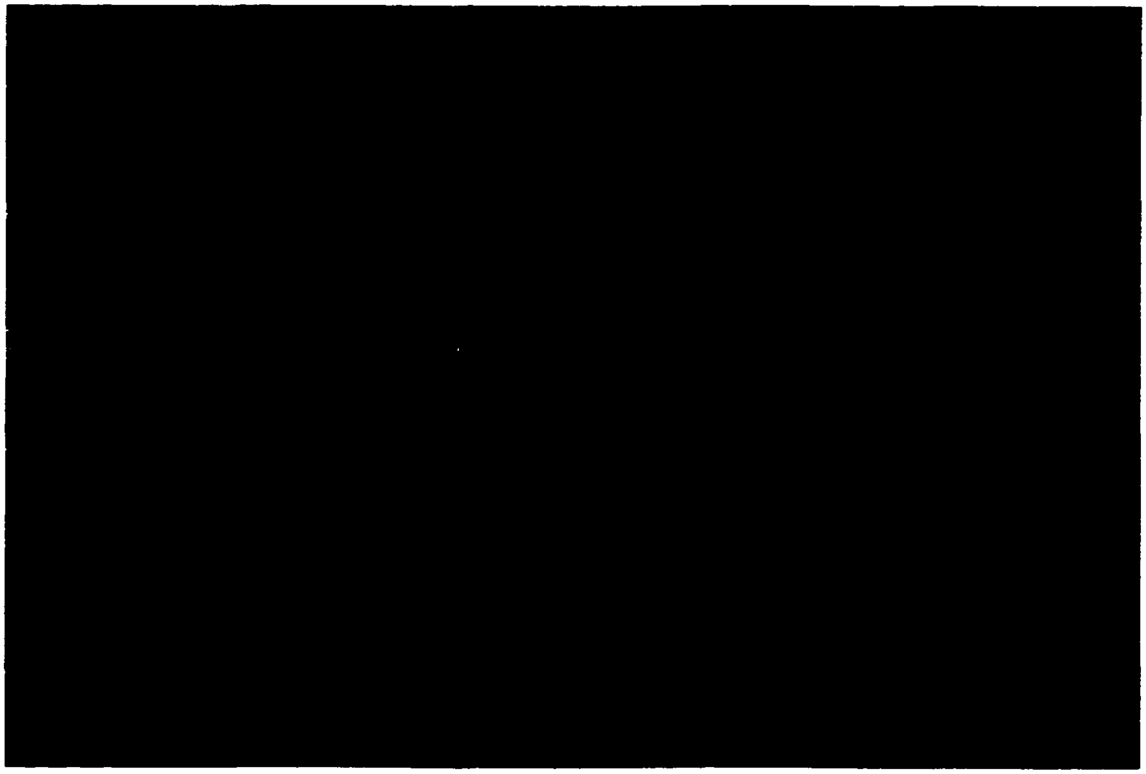


Fig. 6.3.31 Overpass Designed by the Concrete Simulation

The concrete simulation illustrates a successful example of using the geometric object as input for the simulation. A simulation developed for educational purpose usually has low investment and is usually completed by a graduate student with a half-time appointment in two or three months. With limited human and financial resources, it is difficult to create geometric objects dynamically and use the geometric objects as input for the simulation. The concrete module was successful in solving this problem by allowing the user to draw the desired geometric objects as input for the simulation. The concrete simulation can recognize the different shapes of the geometric objects and choose appropriate formula based on the shapes. This is a unique feature of the concrete simulation, and the same technique can be used in developing other engineering simulations.

6.3.9 Piping Network

The piping network module was designed for the Environmental Engineering I course at the University of Oklahoma. Its main purpose was to provide an easily assessed generic solver for pipe networks. Piping networks are a basic problem in civil engineering. The computer is needed for design and analysis due to their complexity, and commercial software is available for this kind of task. It is important however for a civil engineer to understand the theory and concepts behind the automatic analysis. Thus, it is useful to provide an Internet-based semi-automatic solver for piping networks. The students can learn the concepts through exploration.

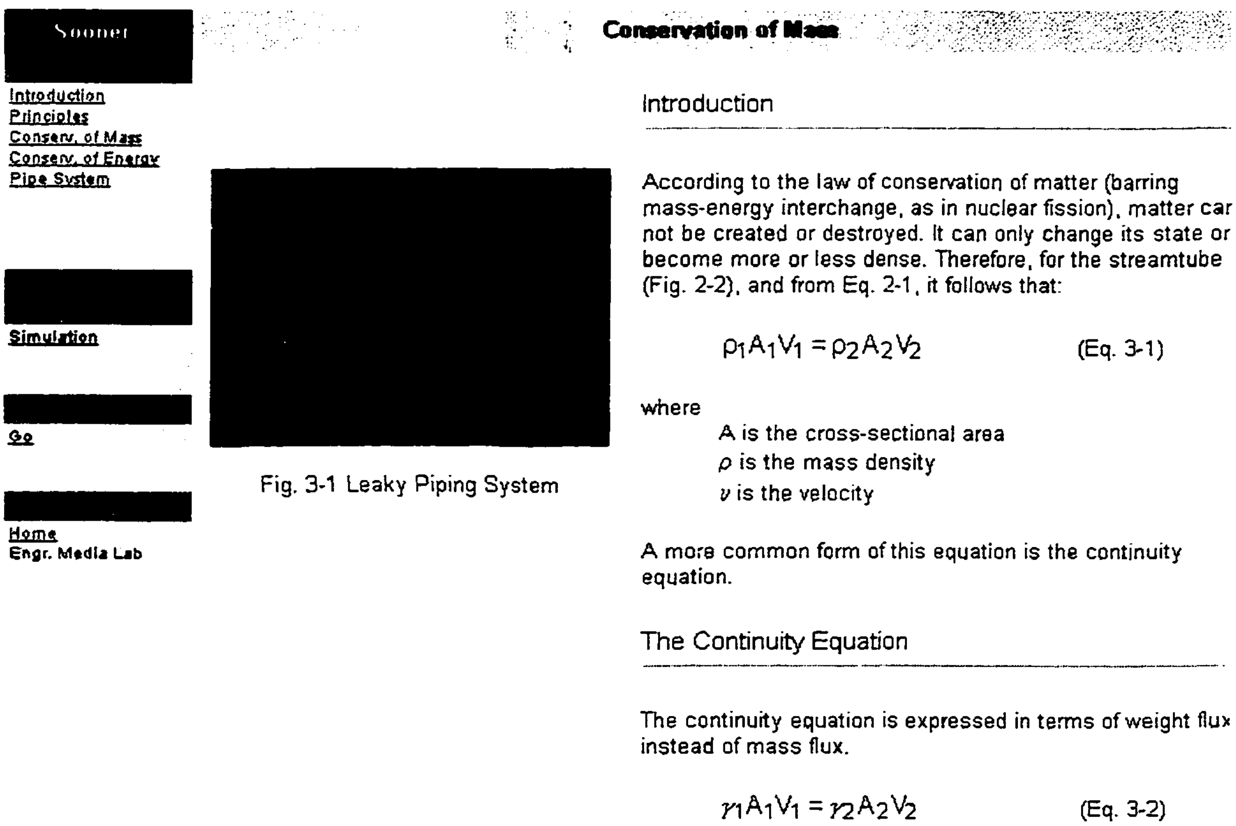


Fig. 6.3.32 Information Section of the Piping Network Module

The information section (Fig. 6.3.32) of the piping network consists of four subtopics: Principles, Conservation of Mass, Conservation of Energy, and Piping System Analysis. These concepts were only briefly covered with text explanations. By studying these subtopics, the user can have a basic understanding of the concepts related to the piping network analysis.

The principles of conservation and related equations, which were explained in the information section, are at the heart of the piping network simulation. Two systems of equations can be used to solve the same network problem. One is a system of Q-Equations, and the other is a system of H-Equations. Numerical methods are used to solve the systems of equations. The system of Q-equations is based on the continuity (conservation of mass) and work-energy principles, and assumes the flows as the principal unknowns. To satisfy the continuity principle, the flow into a junction must be equal to the flow out of the junction (Eq. 6.3.2).

$$QJ_j - \sum Q_i = 0 \qquad (6.3.2)$$

where

QJ_j is the flow out of the junction (demand).

Q_i is the flow into the junction from the pipe i.

To satisfy the work-energy principle, the sum of the head loss around each independent loop must be equal to zero (Eq. 6.3.3).

$$\sum H_{fi} = 0 \qquad (6.3.3)$$

where

H_{fi} is the functional head loss in pipe i.

The head loss can be expressed as a function of discharge via the Hazen-Williams or Manning equation. The system of H-equations is based on the continuity principle and assumes head losses as the principal unknowns. The form of H-equations is the same as Eq. 6.3.2.

The simulation allows the user to draw the piping network dynamically. The lengths of the individual pipes are automatically computed based on a grid system. The pipe diameter and roughness coefficient can be modified. A reservoir can be added to the network, and its elevation can be specified. At each node, a demand can be defined. To solve the system of Q-Equations, one or multiple independent loops may be needed due to the work-energy principle. Theoretically, algorithms exist that can find the necessary independent loops. It is however an important learning process for the user to identify and specify the loops. This simulation, therefore, requires the user to pick the necessary independent loops by clicking on the appropriate areas.

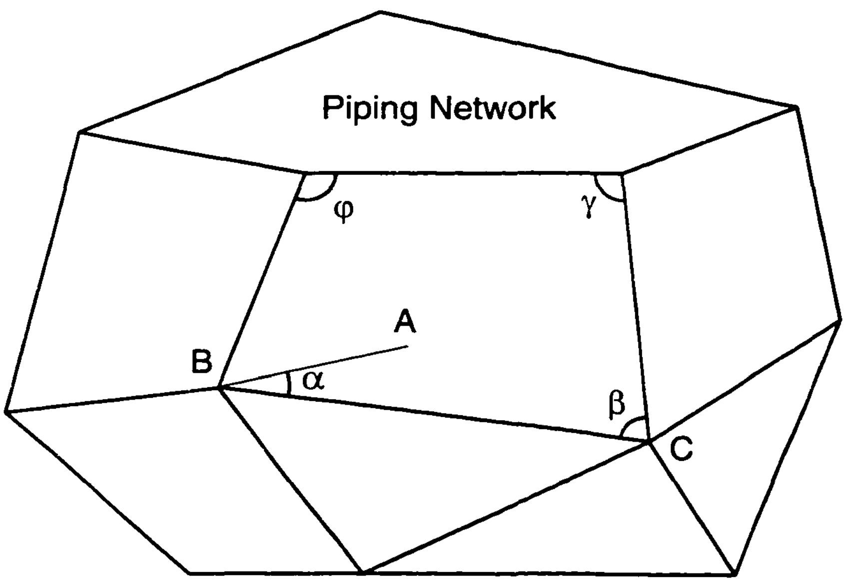


Fig. 6.3.33 Loop Searching Algorithm

An algorithm is needed to search the selected loop, because the loop data are not stored internally in the simulation. The loop-searching algorithm works as follows (Fig. 6.3.33):

1. Obtain the mouse position A.
2. Find the nearest node B to the mouse position. Make sure the line AB has no intersection point with any existing edge besides the nodes. If it has, move to the second nearest node, name it as B, and check the intersection point again.
3. Find all of edges with the common node B. Compute the angles between these edges and line AB. Obtain the edge with the minimum angle and name it as BC. C is the next node of this edge. Record this edge.
4. Again find all of edges with common node C. Delete BC edge from these edges. Formulate the line equation of BC. Find another nodes of these edges and check if they are located on the same side of BC edge as the mouse position A. If yes, compute the angles between the edges and edge BC. The edge with a minimum angle is the desired edge. Record this edge.
5. Repeat step 4 until the edge reaches node B.

The computational results are presented graphically to the user. Flow rates and their directions along the pipes are visually demonstrated (Fig. 6.3.34). Likewise, flow velocities and losses along the pipes are computed and displayed the same way. Pressures and heads at nodes can also be presented if the user clicks appropriate buttons.

The main features of the simulations are as follows:

1. Click the 'Preference' button to set the preferences. The user can specify the unit, pipe diameter, roughness coefficient, and node elevation.

2. Under the 'Pipe' button, the user can choose specific buttons, such as 'Create', 'Move', and 'Delete', to design a piping network.
3. Under the 'B.C.' button, the user can select related buttons to define demands, a reservoir, or independent loops.
4. The user can choose Q-Equation or H-Equation method to solve the problem.
5. Click the 'Solve' button to obtain the solution.
6. Under the 'Solve' button, the user can choose corresponding buttons to demonstrate the flow rate, velocity, and head loss along the pipe as well as the pressure and head at each node.

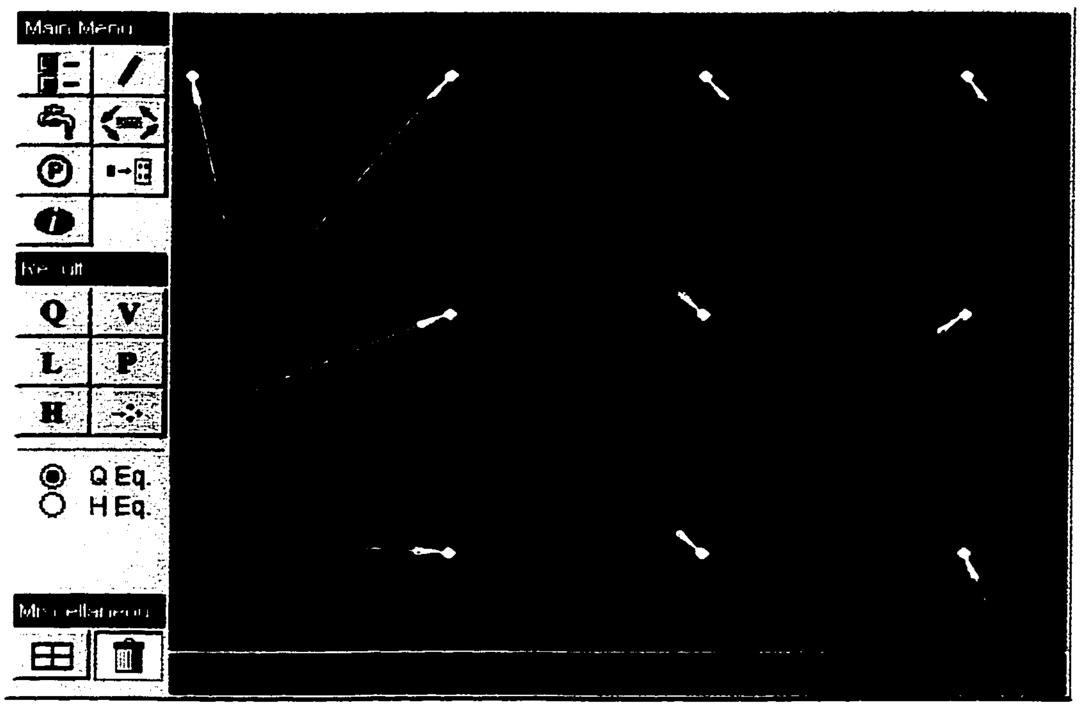


Fig. 6.3.34 Flow Rates and Directions

The piping simulation is a generic application, and can be used to help develop specific applications. One particular application, computation of the system curve and operating point of the network, was a special case. Since the pump can be viewed as a demand with a negative input, it is easy to obtain the system curve. In this case, the computing procedure is the same as the demands with positive input. By changing the negative input, multiple heads associated with the pump can be calculated. The system curve can then be drawn based on the computed data. The user provides the actual pump data, and determines the number of pumps with a series or parallel configuration. When the pump curve is drawn together with the system curve, the operating point can then be found (Fig. 6.3.35). This is useful because the students usually have difficulty in understanding the system curve and operating point.

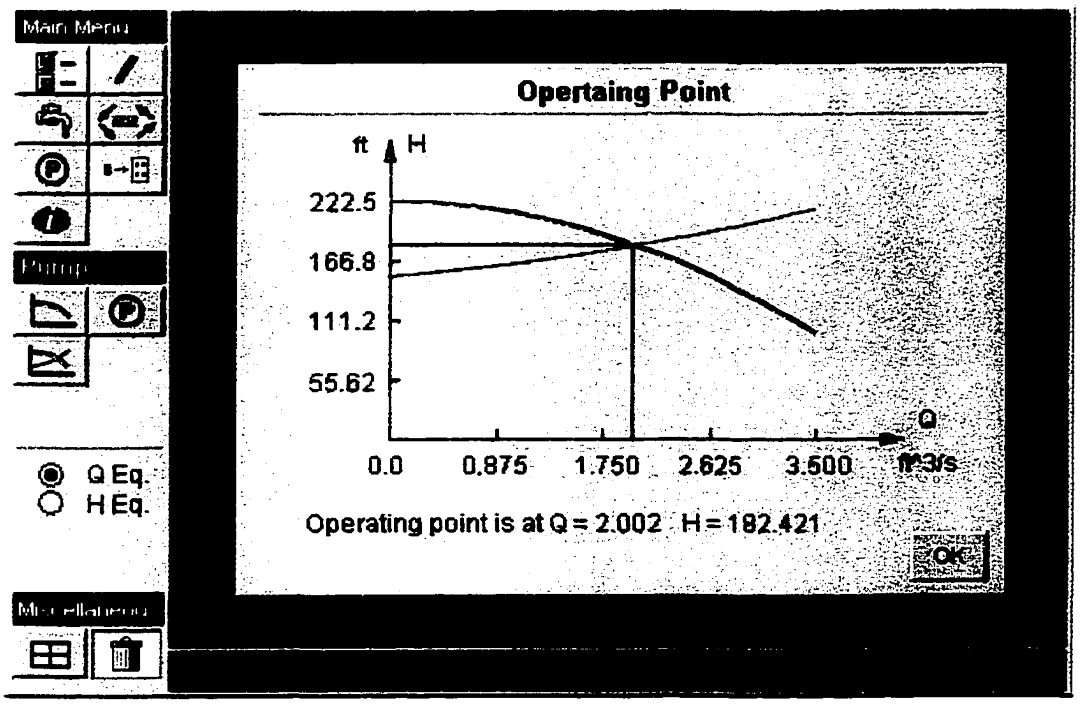


Fig. 6.3.35 System Curve and Pump Curve

Fig. 6.3.36 Piping System Deposited in the 3D Virtual World (Looking from below ground upward)

There are multiple unique features in the piping network simulation. Similar to the structural analysis and concrete modules, it provides an intuitive way to draw, move, and delete the pipes. The user can visually define the reservoir and demands in a straightforward and convenient way. The simulation automatically records the index of each node and pipe. This minimizes the tedious work of preparing the data of the network. The computational results are graphically presented; the user therefore does not need to read the result tables. Once the system curve are computed and drawn, the operating point is found and presented visually to the user. Also, a piping system can be deposited in the virtual world (Fig. 6.3.36).

6.4 Distributed Collaborative Geometric Modeling

6.4.1 Introduction

The Virtual City is not only for engineering education as discussed previously, but also for engineering design. Traditionally, engineers use an expensive CAD/CAE/CAM package to complete design projects. If they are scattered in different locations, they travel and meet to discuss design issues. However, the omnipresence of the Internet has opened a new window to develop unprecedented engineering design tools. These tools can overcome the difficulties related to conventional design tools, such as the lack of collaborative capabilities. The geometric modeling module is one such prototype that internally supports collaboration of remote users. It consists of two components: a client-side geometric modeling application, and a multi-user server application. The client-side application performs geometric modeling while the server-side application manages communication and coordination. Two technologies: Shockwave and Java were mainly used to implement the module. The reason to employ two different technologies is that Shockwave could not shade 3D geometric models at the time this research was done. Java was therefore selected to help shade geometric models generated by Shockwave simulations.

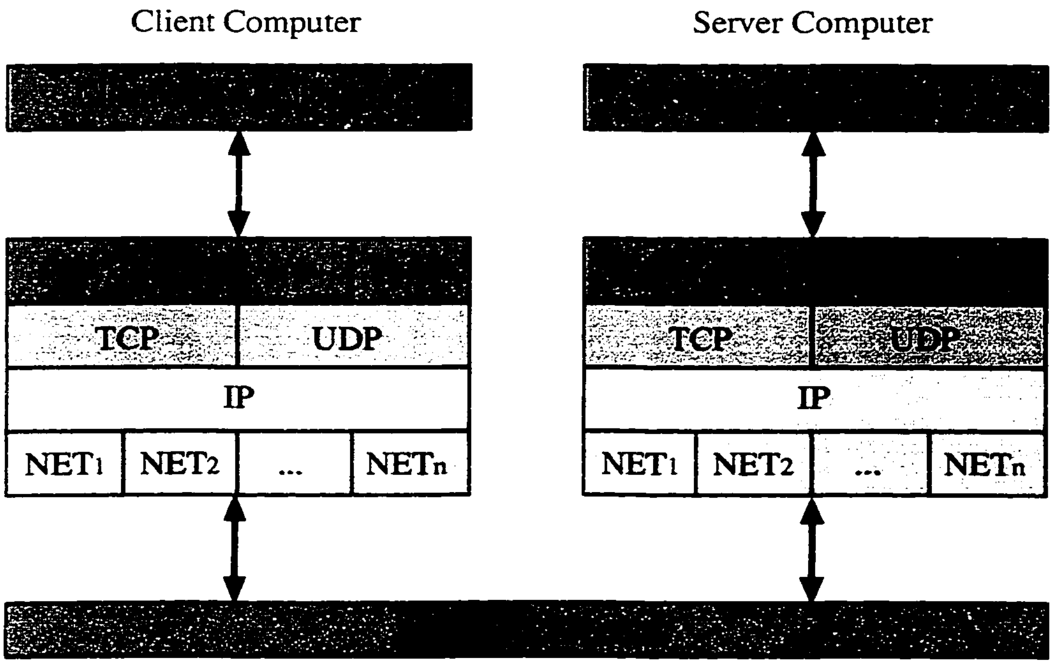
6.4.2 Server-side Application

Theoretically, applications can communicate with each other directly through the Internet, but they need to know each other's IP addresses in advance. This is particularly inconvenient when a user's computer is configured to obtain a dynamic IP address. Also, these applications cannot run inside a browser, because the browser restricts direct communication between client computers for security reasons. Therefore another approach was adopted, which uses a server-side application to avoid difficulties associated with direct communications. The browser-based client-side applications can easily talk to the server-side application. The server-side application can then route messages to interested client-side applications.

6.4.2.1 Fundamentals of the Internet Used in the Geometric Modeling Module

The communication between the server-side and client-side applications through the Internet is a complex procedure, however, the user only experiences the sending and receiving of data. To explain how data is transmitted over the Internet, a four-layer model is often used (Fig. 6.4.1). At the lowest level are various networking protocols, denoted as NET1, NET2, etc. The second layer consists of the Internet Protocol (IP). The third layer is a transport layer that contains two main protocols - the Transmission Control Protocol (TCP) and the User Datagram Protocol (UDP). Above the third layer is an application protocol layer that consists of a number of protocols, such as the File Transfer Protocol (FTP) and the HyperText Transport Protocol (HTTP).

When the client-side application of the client computer sends data to a server-side application of the server computer, the data usually goes through the application protocol layer, the transport layer, the IP layer, and finally the first layer to the physical link. When the server-side application of the server computer receives data from the client-side application of the client computer, the data usually goes from the physical link to the first layer, the IP layer, the transport layer, and finally the application protocol layer. In practice, the networking Application Programming Interface (API) is used to hide the complexity and details of protocols.



IP = Internet Protocol
TCP = Transmission Control Protocol
UDP = User Datagram Protocol
FTP = File Transfer Protocol
HTTP = HyperText Transport Protocol
TFTP = Trivial File Transport Protocol

Fig. 6.4.1 Internet Four-layer Model

6.4.2.2 Multi-user Server

The networking API was used to develop the client-side geometric modeling and server-side multi-user applications of the Virtual City. The server-side multi-user application plays an essential role in collaboration. It includes two programs: a Shockwave multi-user server and a Java multi-user server. Both are capable of receiving and delivering packets to clients-side applications (Fig. 6.4.2). The reason for two multi-user servers is that the geometric modeling module utilized two different Internet technologies: Shockwave and Java. Shockwave simulations can only communicate with the Shockwave multi-user server, and Java applets can be easily programmed to talk with the Java multi-user server.

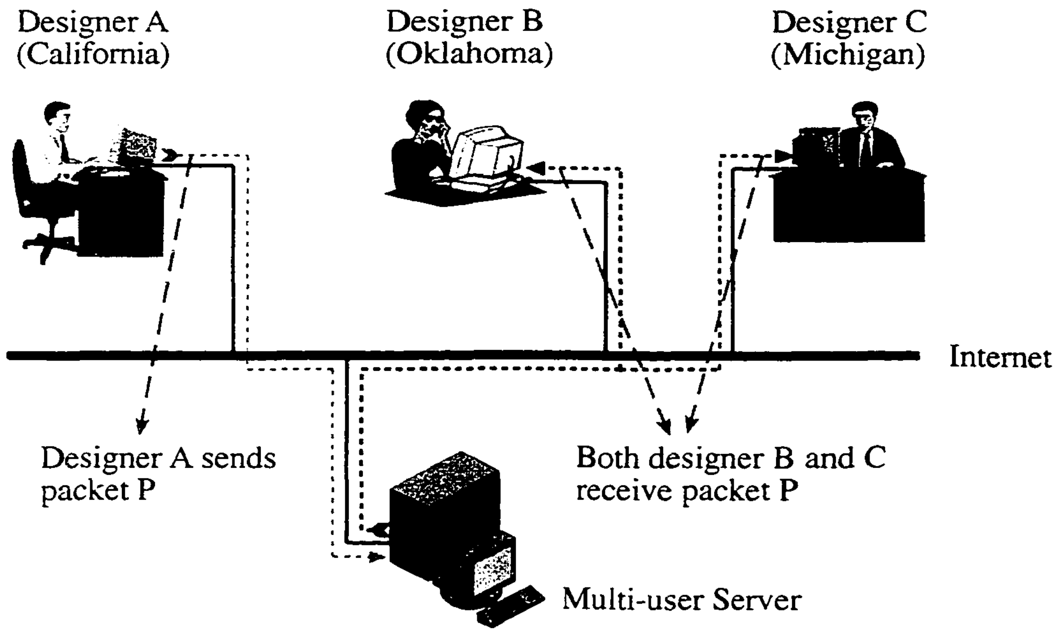


Fig. 6.4.2 Function of Multi-user Server

The Shockwave multi-user server works with the Shockwave simulation of the client-side geometric modeling module. The Java multi-user server, which was developed for the collaborative geometric modeling and engineering analysis modules, delivers the packet of one client's applet to the applets of other clients. The design concepts of both servers are similar, and both keep a table for each design team. When the user starts the geometric modeling application, both the Shockwave simulation and Java applet send a registration packet with the name of design team, client's IP address, and port numbers to their corresponding multi-user servers. The multi-user servers record the data in the related table. Because the IP address and port number is unique at any given time, the

Shockwave multi-user server then uses them to communicate with the Shockwave simulation, and the Java multi-user server uses them to talk with the Java applet. As the design object is shared only in the same design team, members are not allowed to communicate between different design teams.

6.4.2.3 Design of Java Multi-user Server

The Shockwave multi-user server is a standard extension of the Director program. There was no need to develop a new one for the Shockwave simulation. However, no standard Java multi-user server was available. Java was used to design a Java multi-user server for the distributed collaborative geometric modeling and engineering analysis module. Socket implementation was chosen, because it is widely accepted in the networking world. Both TCP socket and UDP socket were used. Since UDP is a connectionless protocol, only unreliable channels are provided. Due to an underlying limitation in the size of UDP packets, the maximum size of a packet that can be sent in one time is 8 Kbytes. No data priority is currently considered with the packet.

Internally, a session manager was used to control communication between team members in the Java multi-user server. When users log into the environment, they have to provide a team account name, username, and password. As the team account name is unique in the environment, it is used as the name of the session. If the user is the first team member to log in the environment, a new session is initiated, and named after the team account. Multiple communication channels associated with the session are created simultaneously. Each channel corresponds with a particular action. Other team members can then join the session and communication channels. It is highly desirable to use different channels for different actions. This is because (in this case) only one specific action is associated with each channel. When an appropriate command message is sent to a particular channel, the channel's consumer can take action easily and does not need to assess how to act based on the received message. The channel uses an event model, and takes action only when receiving a command message. For example, when one team member changes the color of the design object, a command message is automatically sent to the color channel, and therefore the consumer of the color channel updates the computers of other team members. When no event occurs, the consumer of the channel is idle. This is particularly efficient because no computing power is used when nothing happens.

In a collaborative environment, discussion of design ideas before taking actions is encouraged. A chat room, therefore, was designed to allow the users to exchange ideas. When multiple participants are working on the same design object, they are strongly encouraged to coordinate their actions. This is because design is a constructive activity and makes sense for participants communicate with each other in a collaborative environment.

6.4.3 Client-side Application

Similar to the server-side application, the client-side geometric modeling application also consists of two programs: a Shockwave simulation and a Java applet. The Shockwave simulation generates 3D wireframe models (Fig. 6.4.3), and the Java applet shades them (Fig. 6.4.4). The applet was developed using Java 1.3 and Java 3D 1.2.1. In order to run the applet, a Java 1.3 plug-in and a Java 3D 1.2.1 plug-in are necessary to be downloaded from the web site of Sun Microsystems and installed. If the user wants to run the applet while no Java 1.3 plug-in is available, the browser will automatically ask the user if he/she wants to download the Java 1.3 plug-in. If the user says 'yes', the Java 1.3 plug-in will be automatically downloaded and installed. However, the user has to download the Java 3D 1.2.1 plug-in manually.

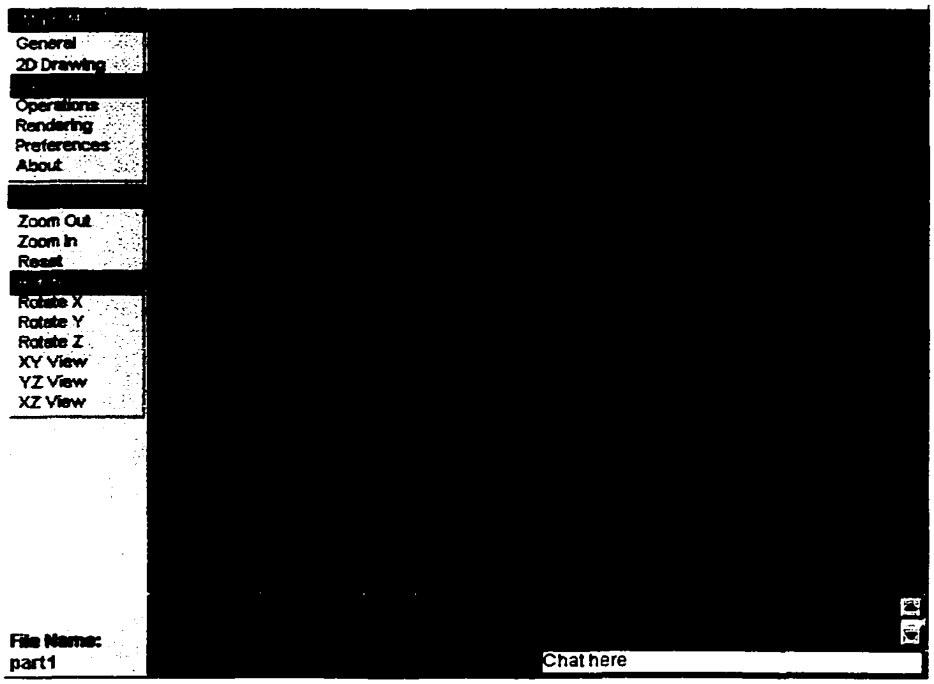


Fig. 6.4.3 Shockwave Movie for Creating the 3D Wireframe Model

The general procedure of building a geometric model involves a number of steps. First the user creates a 3D wireframe model, assigns it a name, and saves it on the server. The user then starts the Java applet, and selects the same name given to the wireframe model. The Java applet loads the geometric model data generated by the Shockwave simulation from the server, renders it, and displays it. Both work simultaneously to display the same model. If the user makes any change to the 3D wireframe model, the change will be propagated to the model automatically in the Java applet, because both of them share the same model name. As discussed previously, the Shockwave simulation talks to the Shockwave multi-user server while the Java applet communicates with the Java multi-user server. Both are real-time collaborative applications.

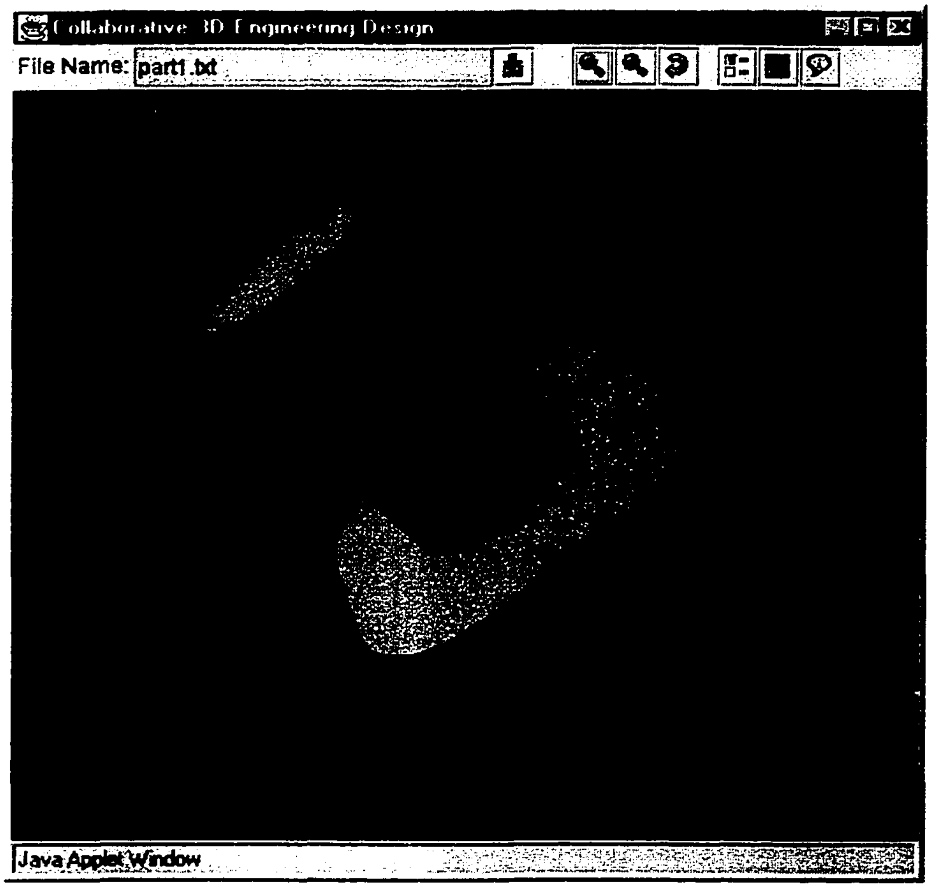


Fig. 6.4.4 Java Applet for Shading the 3D Model

6.4.3.1 Fundamentals of Computer Graphics Used in the Client-side Application

To develop the client-side geometric modeling application, computer graphics concepts were used. The main purpose of these concepts is to display a 3D object efficiently on a 2D screen. Among these concepts, change of coordinate system, transformation, and projection are the fundamentals of the geometric modeling application. These concepts were programmed in the geometric modeling application, and are discussed mathematically in the following paragraphs.

In the geometric modeling application, the change of coordinate system was realized by mathematical operations. The user defines a local coordinate system to draw a 2D cross section. The vertices and edges in the local coordinate are then mapped into the global coordinate system for storage. The following paragraphs explain how to change the coordinate system.

A frame is defined by both the reference point and the basis vectors and can represent all points and vectors unambiguously. To represent both points and vectors in a systematic way, homogeneous coordinates are used in the geometric modeling application. In the frame specified by $(v_1,\ v_2,\ v_3,\ P_0)$, any point P can be written uniquely as

$$P = \alpha_1 v_1 + \alpha_2 v_2 + \alpha_3 v_3 + P_0 \qquad (6.4.1)$$

The point P can also be represented as a column matrix in homogeneous coordinates

$$\mathrm{p} = \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ 1 \end{bmatrix} \qquad (6.4.2)$$

Similarly, any vector w in the frame $(v_1,\ v_2,\ v_3,\ P_0)$ can be written uniquely as

$$w = \delta_1 v_1 + \delta_2 v_2 + \delta_3 v_3 \qquad (6.4.3)$$

The vector w can be represented as a column matrix in homogenous coordinates

$$a = \begin{bmatrix} \delta_1 \\ \delta_2 \\ \delta_3 \\ 0 \end{bmatrix} \qquad (6.4.4)$$

Both the points and vectors therefore can be represented as column matrices.

Assume (v_1, v_2, v_3, P_0) and (u_1, u_2, u_3, Q_0) are two frames, the basis vectors and reference point of the second frame can be expressed in terms of the first frame as

$$\begin{bmatrix} u_1 \\ u_2 \\ u_3 \\ Q_0 \end{bmatrix} = M \begin{bmatrix} v_1 \\ v_2 \\ v_3 \\ P_0 \end{bmatrix} \qquad (6.4.5)$$

M is a matrix, which has the form

$$M = \begin{bmatrix} \gamma_{11} & \gamma_{12} & \gamma_{13} & 0 \\ \gamma_{21} & \gamma_{22} & \gamma_{23} & 0 \\ \gamma_{31} & \gamma_{32} & \gamma_{33} & 0 \\ \gamma_{41} & \gamma_{42} & \gamma_{43} & 1 \end{bmatrix} \qquad (6.4.6)$$

If a is a vector or a point in frame (v_1, v_2, v_3, P_0) and b is a vector or point in frame (u_1, u_2, u_3, Q_0), the following is a general equation used to change coordinate systems

$$a = M^T b \qquad (6.4.7)$$

This equation was programmed in the client-side geometric modeling application. By applying this equation, any vector and vertex in one coordinate system can be converted easily into another system.

Transformation is the second essential concept used in developing the geometric modeling application. Translation, rotation, and scaling are three elements of transformation. Transformation can be realized by multiplying a matrix if the points and vectors are represented using homogeneous coordinates. The following equations were used in programming transformation in the geometric modeling application.

If point p is moved to p' by a displacement vector $(\alpha_x, \alpha_y, \alpha_z)$, the following equation is employed to perform translation

$$p' = Tp \tag{6.4.8}$$

where

$$T = \begin{bmatrix} 1 & 0 & 0 & \alpha_x \\ 0 & 1 & 0 & \alpha_y \\ 0 & 0 & 1 & \alpha_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{6.4.9}$$

If point p is scaled to p' by $\beta_x, \beta_y, \beta_z$ along x, y, z axis, the following equation is used to perform scaling.

$$p' = Sp \tag{6.4.10}$$

where

$$S = \begin{bmatrix} \beta_x & 0 & 0 & 0 \\ 0 & \beta_y & 0 & 0 \\ 0 & 0 & \beta_z & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{6.4.11}$$

If point p is rotated to p' about the z axis by an angle θ, the following equation is used to perform rotation.

$$p' = R_z p \tag{6.4.12}$$

where

$$R_z = \begin{bmatrix} \cos\theta & -\sin\theta & 0 & 0 \\ \sin\theta & \cos\theta & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{6.4.13}$$

Similar equations can also be obtained for rotation about the x and y axis.

Projection is the third essential concept used in programming the geometric modeling application. Projection's main purpose is to display a 3D object correctly on a 2D screen. There are two kinds of projections: perspective and parallel. Mathematically, they can be obtained by multiplying a projection matrix. Perspective projection assumes that there exists a center of projection (COP) (Fig. 6.4.5). All of the projectors meet at COP. If COP is moved to infinity, the projectors become parallel and the projection is called parallel projection (Fig. 6.4.6).

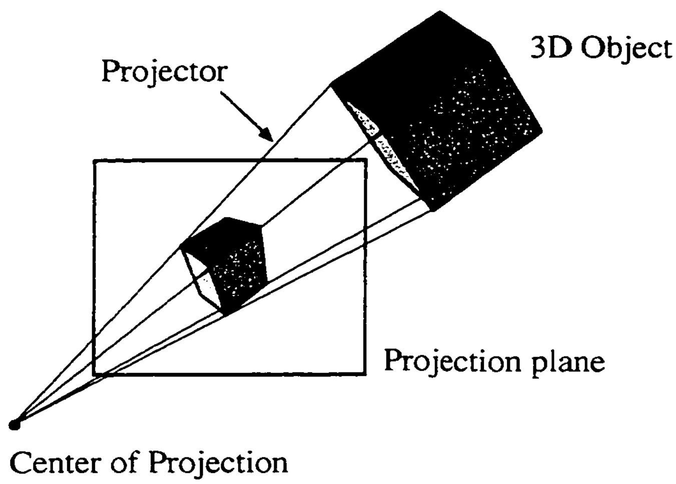


Fig. 6.4.5 Perspective Projection

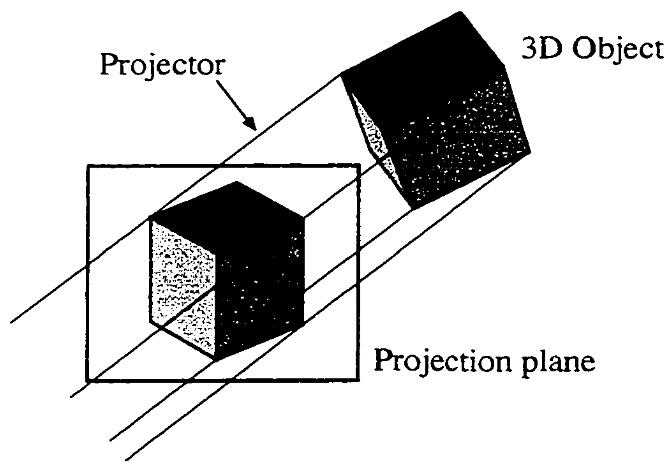


Fig.6.4.6 Parallel Projection

Both projections were used in the geometric modeling application. Parallel projection was used in the Shockwave geometric modeling simulation due to its ease of implementation. Perspective projection gives the user a better impression of 3D effect, and was employed in the Java shading applet.

6.4.3.2 Data Structures

Besides the graphic concepts, the data structure used to store 3D data is also of particular importance. This is because all of the 3D operations were designed on top of the data structure. In this research, a B-Rep data structure is used, because it can be easily implemented. The B-Rep data structure stores the basic elements composing the boundary of a solid: the vertices, the edges, and the faces. Table 6.4.1 shows the three-part data structure representing the solid in Fig. 6.4.7.

Table 6.4.1 B-Rep Data Structure

Vertex Table		Edge Table		Face Table	
Vertex	Coordinates	Edge	Vertices	Face	Edges
V_1	X_1, Y_1, Z_1	E_1	V_1, V_2	F_1	E_4, E_3, E_2, E_1
V_2	X_2, Y_2, Z_2	E_2	V_2, V_3	F_2	E_5, E_{12}, E_8, E_4
V_3	X_3, Y_3, Z_3	E_3	V_3, V_4	F_3	E_9, E_5, E_1, E_6
V_4	X_4, Y_4, Z_4	E_4	V_4, V_1	F_4	E_2, E_7, E_{10}, E_6
V_5	X_5, Y_5, Z_5	E_5	V_1, V_5	F_5	E_3, E_8, E_{11}, E_7
V_6	X_6, Y_6, Z_6	E_6	V_2, V_6	F_6	$E_9, E_{10}, E_{11}, E_{12}$
V_7	X_7, Y_7, Z_7	E_7	V_3, V_7		
V_8	X_8, Y_8, Z_8	E_8	V_4, V_8		
		E_9	V_5, V_6		
		E_{10}	V_6, V_7		
		E_{11}	V_7, V_8		
		E_{12}	V_8, V_5		

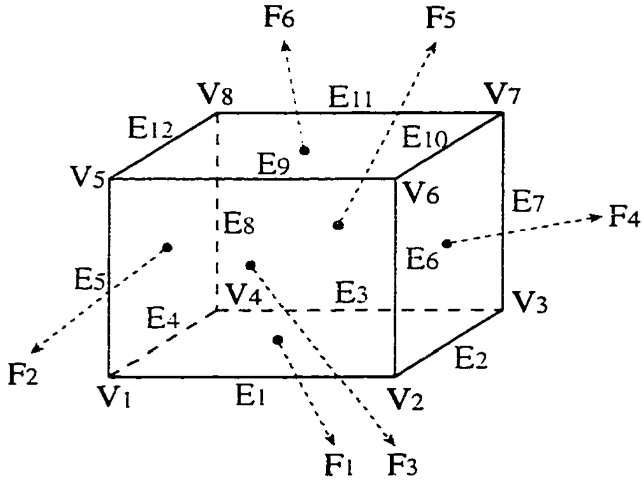


Fig. 6.4.7 Data Structure Used for Representing a Solid

Each row of the vertex table stores the x, y, and z coordinates of the vertices. These coordinates are defined with respect to the world coordinate system. The edge table stores the end vertices of each edge. The face table stores the boundary edges for each face. The order of edges for each face is obtained by traversing it counterclockwise when viewed from the outside. By storing the edges in this way, the inside and the outside of the solid can be distinguished. Both the Shockwave simulation and the Java applet used the B-Rep data structure.

In addition to the B-Rep data structure, the stack data structure was also used extensively in developing the Shockwave geometric modeling simulation. Shockwave lingo is a special programming language, which has a cast library to manage all of the visual entities. To display these visual entities on the stage, they must be placed in different channels. The channel is a container to store visual entities in Director. Since all of the line entities are dynamically created and may be deleted after creation, it was a challenge to manage the free channels efficiently. One solution is to use stack data structures.

Stacks are called the last-in, first-out data structures, which store a set of objects in a primitive data structures such as arrays and restrict operations such as 'delete' and 'insert' to apply only to the "top" of the data structure. In stack terminology, the delete operation is called 'pop', and the insert operation is called 'push'. A stack data structure can be used to remember the past information, so this information will be available when needed. Another important usage of the stacks is that stacks can be employed to manage free space. Using stacks, some algorithms can be implemented easily, such as the non-recursive inorder, and preorder and postorder traversals of the binary trees. The specification of an abstract data type for a stack usually has six key operations: create an empty stack, check if the stack is empty, get the object from the top of the stack without removing it, remove the object from the top of the stack, insert a new object on the top of the stack, and return the number of current objects in the stack.

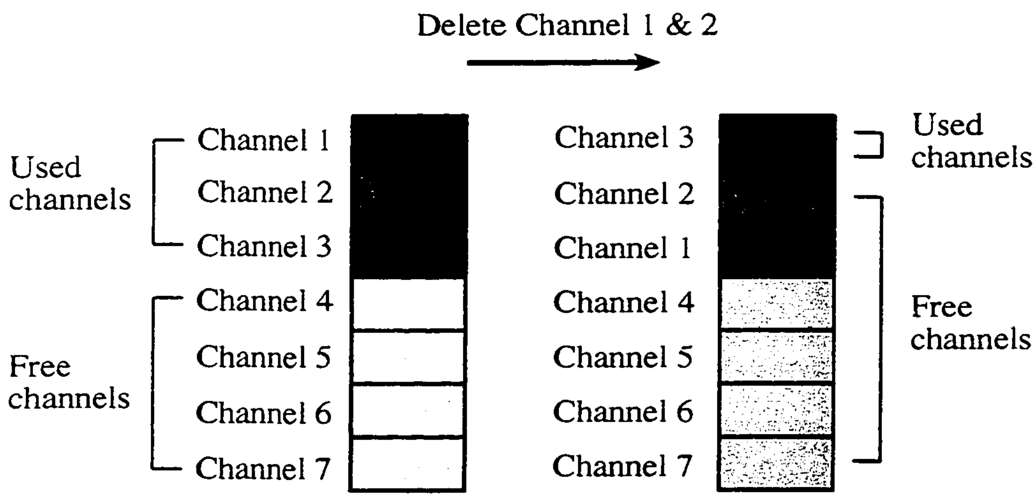


Fig. 6.4.8 Stack Data Structure

Shockwave Lingo does not support a built-in stack data structure, but has a list data structure that can be used to simulate the stack data structure. The concept of the stack data structure can then be used to manage the free sprite channels and the naming of the cast members (Fig. 6.4.8). Free channels are pushed into a stack when the application starts. A channel is popped out from the stack when the application needs it. If a line on that channel is deleted, that channel is free again and is pushed back into the stack for later use. Using a stack, the problem of keeping track of the free channels in the Shockwave simulation was efficiently solved. The naming of the cast members was solved using the same technique. Appendix B illustrates using a list in Lingo to simulate the functions of stack data structures.

6.4.3.3 Implementation Algorithms

In addition to data structures, numerous algorithms were used in programming the geometric modeling application. Among these algorithms are the drawing operations: 'Corner', 'Trim', and 'Round'. As an example, the algorithm to compute an intersection point is discussed in the following paragraph. This example shows the importance of choosing efficient algorithms.

Assume there are two lines. The first line is defined by $P_1(x_1, y_1, z_1)$ and $P_2(x_2, y_2, z_2)$ while the second line by $P_3(x_3, y_3, z_3)$ and $P_4(x_4, y_4, z_4)$. The intersection point is needed. There are numerous ways to compute the intersection point. The parametric method is more effective, because additional useful information can be obtained in addition to the intersection point.

In a parametric form, any point on the first line can be represented as

$$\begin{cases} x = x_1 + t_1(x_2 - x_1) \\ y = y_1 + t_1(y_2 - y_1) \\ z = z_1 + t_1(z_2 - z_1) \end{cases} \qquad (6.4.14)$$

Likewise, any point on the second line can be represented as

$$\begin{cases} x = x_3 + t_2(x_4 - x_3) \\ y = y_3 + t_2(y_4 - y_3) \\ z = z_3 + t_2(z_4 - z_3) \end{cases} \qquad (6.4.15)$$

Where t_1 and t_2 are parameters that can be any value.

As the intersection point is needed, the following equations should be satisfied.

$$\begin{aligned} x_1 + t_1(x_2 - x_1) &= x_3 + t_2(x_4 - x_3) \\ y_1 + t_1(y_2 - y_1) &= y_3 + t_2(y_4 - y_3) \\ z_1 + t_1(z_2 - z_1) &= z_3 + t_2(z_4 - z_3) \end{aligned} \qquad (6.4.16)$$

By solving the first two equations, the values of t_1 and t_2 can be obtained. They are then inserted into the third equation. If the third equation is satisfied, there exists an intersection point. Otherwise, no intersection point exists between these two lines.

If an intersection point exists between two lines, t_1 and t_2 can be used to determine the location of the point. If $0 \le t_1 \le 1.0$, the intersection point is located between P_1 and P_2. If $t_1 < 0$ or $t_1 > 1.0$, the intersection point is located outside P_1 and P_2.

6.4.3.4 Functions of the Geometric Modeling Application

The geometric modeling application consists of two components: a Shockwave simulation and a Java applet. Their interfaces were also designed using two different technologies: Shockwave and Java. The functions of the two components are therefore different. The Shockwave simulation is used for building geometric models while the applet is for shading models.

The Shockwave simulation is a simple geometric modeling tool that allows the user to draw any 2D section, extrude it, modify it, save it on the server, and retrieve it from the server. The Interface of the Shockwave simulation contains three areas: the menu area for displaying menus, the working area for displaying geometric models, and the message area for displaying input and output messages and a chat room. The menu is designed with two levels. The main menu window is always visible while the sub-level menu windows become visible only when the user clicks the corresponding main menu items (Fig. 6.4.9). There are seven menu items in the main menu window: 'General', '2D drawing', 'View', 'Operation', 'Rendering', 'Preference', and 'About'. Among them, only the first four main menu items have corresponding sub-level menu windows. All of the operations propagate automatically among the shared users. Numerous remote users can therefore work on the same geometric model simultaneously.

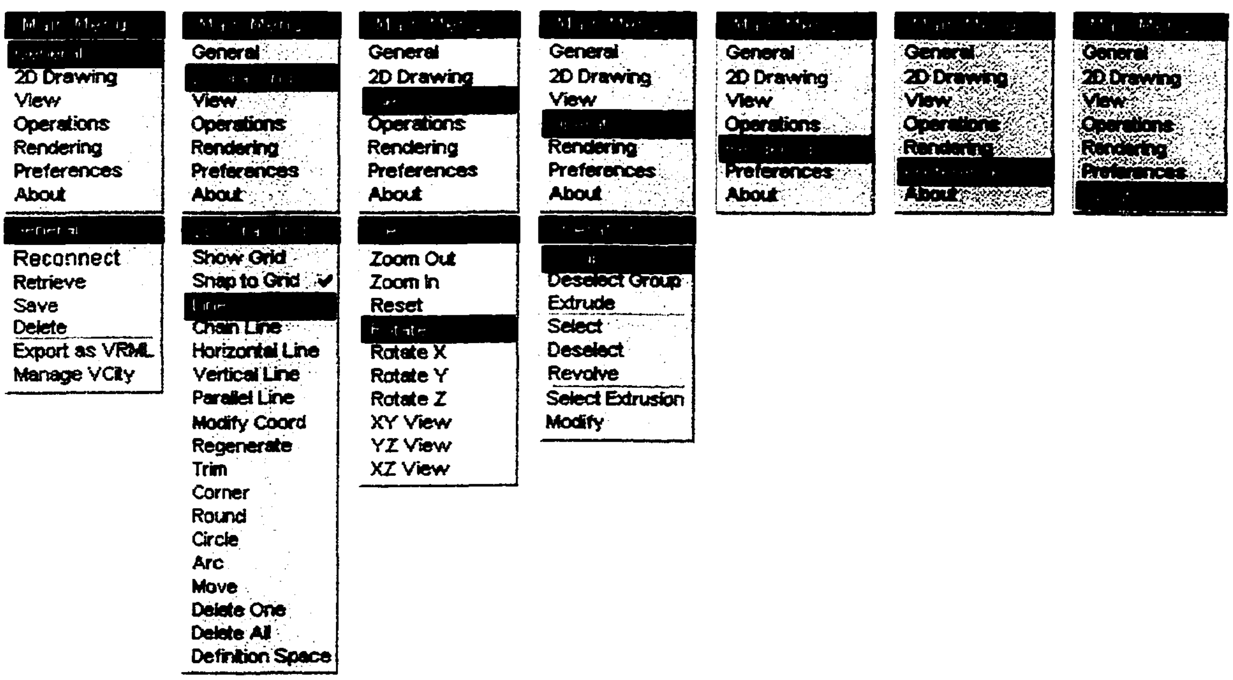


Fig. 6.4.9 Menu Levels of the Geometric Modeling Simulation

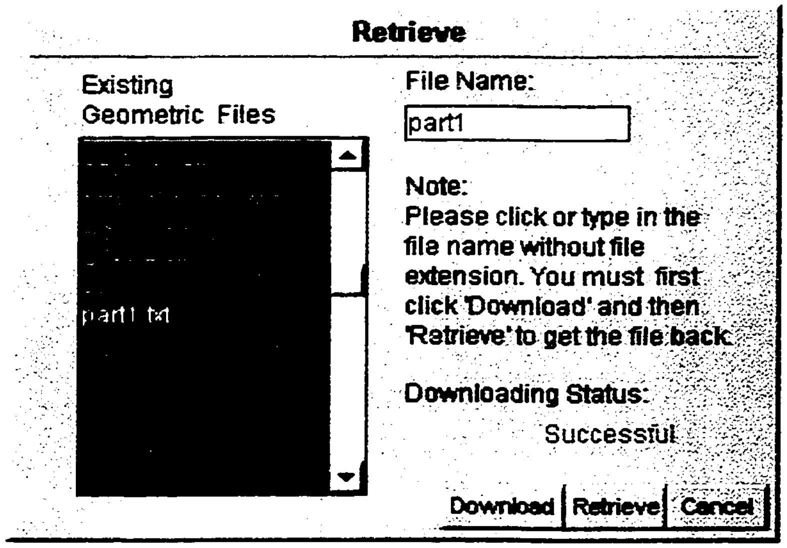


Fig. 6.4.10 Pop-up Window for Retrieving Geometric Files

There are six menu items in the 'General' sub-level menu window: 'Reconnect', 'Retrieve'. 'Save', 'Delete', 'Export as VRML', and 'Manage City'. In the Shockwave multi-user server, there is an idle timer to control connections. If no activity occurs in a connection for a given time, the multi-user server will drop that connection. However, the user can establish the connection again by clicking on the 'Reconnect' menu item. If the user clicks on the 'Retrieve' menu item, the user can download data files from the server and then retrieve geometric models (Fig.6.4.10). If the user clicks on the 'Save' menu item, the user can specify a file name to the current geometric model and save it on the server (Fig. 6.4.11). If the user employs the same file name as an existing file, the existing file will be overwritten. If the user clicks on the 'Delete' menu item, the user can delete any existing geometric data file. Also, the geometric model can be exported in a VRML format and deposited in the 3D virtual world if the user clicks on the 'Export as VRML'. Figure 6.4.12 illustrates buildings designed by the geometric modeling application. Multiple objects may be deposited in the Virtual World. The user can manage the Virtual World by deleting some or all of these objects if he/she clicks on the 'Manage City' menu item.

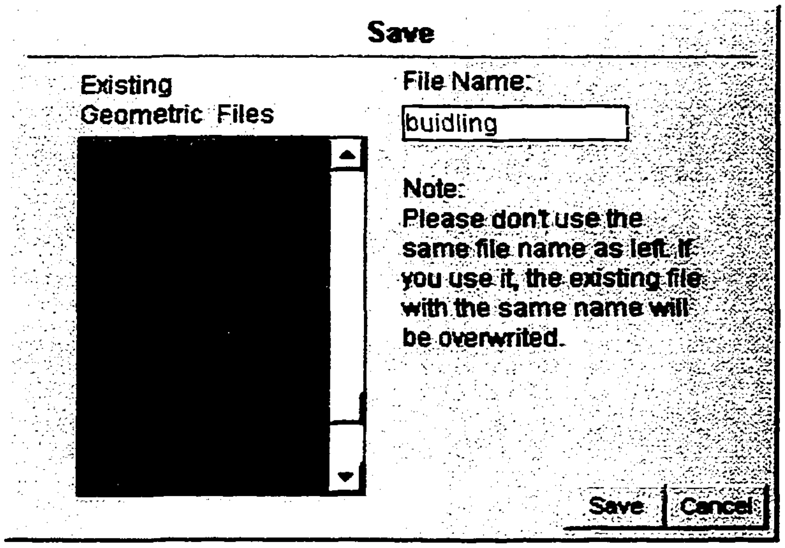


Fig. 6.4.11 Pop-up Window for Saving Geometric Files

Fig. 6.4.12 Buildings Designed by the Geometric Modeling Application

The ‘2D Drawing’ sub-level menu window contains eighteen menu items: 'Show Grid', 'Snap to Grid', 'Line', 'Chain Line', 'Horizontal Line', 'Vertical Line', 'Parallel Line', 'Modify Coord', 'Regenerate', 'Trim', 'Corner', 'Round', 'Circle', 'Arc', 'Move', 'Delete One', 'Delete All', and 'Definition Space'. Each menu item is associated with a specific drawing operation. The user can select appropriate menu items to draw 2D sections on the working area. If the user clicks on a menu item, the menu item is selected and becomes highlighted. A grid is used to help locate the positions. The user can choose to show the grid by clicking on the 'Show Grid' item. The grid can be activated or deactivated by clicking on the 'Snap to Grid' item. If the 'Line' item becomes highlighted, a line with random direction can then be drawn by "click-and-drag" motion. If the user selects the 'Chain Line' item, clicking different locations can create chain lines. If the user chooses the 'Horizontal Line' or 'Vertical Line' item, horizontal or vertical lines can be generated by "click-and-drag" motion. If the 'Parallel Line' is highlighted, parallel lines can be created based on a specific line. If accurate coordinates are necessary, the user can click on the particular node and type in the actual coordinate values when the 'Modify Coord' item is highlighted. Clicking on the 'Regenerate' item updates the geometric model based on the inputted coordinate values. A line can be used to trim other lines when the 'Trim' item is selected. Two intersecting lines can generate a corner when the 'Corner' item is picked. To create a corner, the user picks two desired lines, and then indicates the quadrant. When the 'Round' item is highlighted, the user can generated a round corner between two lines by providing a radius value. If the 'Circle' or 'Arc' item is selected, the user can create a circle or an arc. The circle and the arc are simulated by a number of lines. As a result, the whole circle and arc cannot be moved at the same time. The lines can be deleted individually or they can be deleted as a whole. When the 'Move' item is highlighted, the entire line can be moved if the user clicks and drags the middle of the line. The end of the line can be moved if one clicks and drags the end of line. Individual lines can be deleted when 'Delete One' item is chosen. If the user clicks on 'Delete All' item, the whole geometric model is deleted immediately. There are two coordinate systems existing at the same time: the World Coordinate System and the Definition Coordinate System. Three-dimensional data is stored in the World Coordinate System. Two-dimensional drawing is conducted in the Definition Coordinate System. The user therefore has to determine the Definition Coordinate System before drawing a 2D section. When the 'Definition Space' is highlighted, the user can selected the local Definition Coordinate System to conduct 2D drawing.

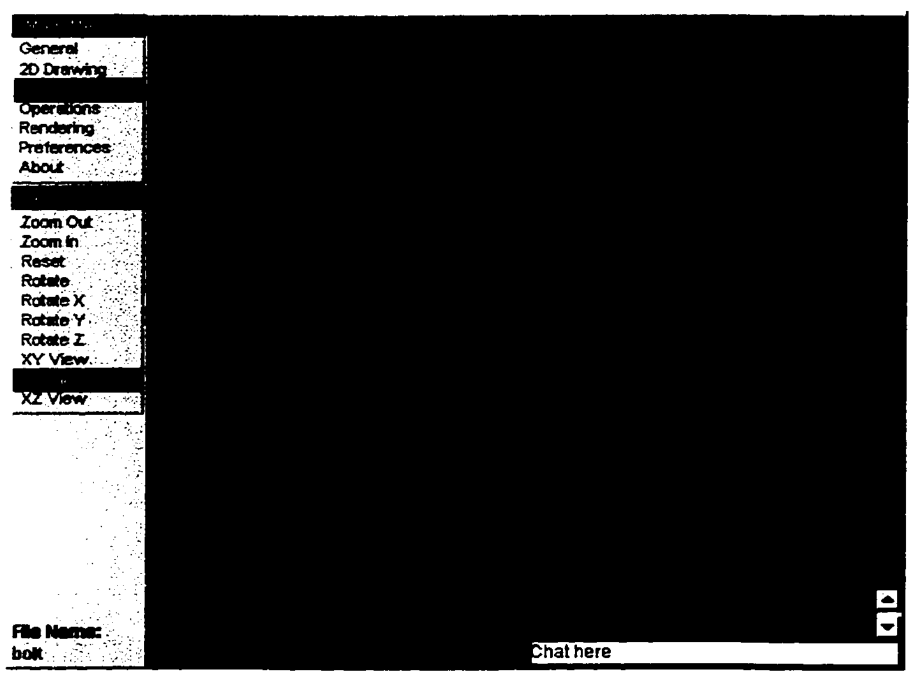


Fig. 6.4.13 YZ View of the Bolt

The ‘View’ sub-level menu window includes ten items: 'Zoom Out', 'Zoom In', 'Reset', 'Rotate', 'Rotate X', 'Rotate Y', 'Rotate Z', 'XY View', 'YZ View', and 'XZ View'. These menu items provide interactive viewing operations. The user can zoom in, zoom out, and reset the scale of 3D models by clicking on the 'Zoom Out', 'Zoom In', and 'Reset' items. The simulation supports free rotation as well as rotation about the x, y, and z axes if the user clicks on the 'Rotate', 'Rotate X', 'Rotate Y', and 'Rotate Z' items. XY, YZ, and XZ views can also be obtained when 'XY View', 'YZ View', and 'XZ View' items are clicked (Fig. 6.4.13).

There are seven items in the ‘Operation’ sub-level menu window: 'Group', 'Deselect Group', 'Extrude', 'Select', 'Deselect', 'Revolve', 'Select Extrusion', and 'Modify'. These menu items provide tools to generate 3D models. Two operations - extrusion and revolution, are currently supported. A closed section can be extruded at a specified distance to create a 3D model. The user first draws a closed 2D section in the definition coordinate system. He/she then clicks on the 'Group' item to highlight it. The user next picks two consecutive lines to select the whole section. Last, he/she clicks on the 'Extrude' item to specify the distance of the extrusion. If the user wants to pick a different section, he/she can deselect the current one by clicking on the 'Deselect Group'. A profile around an axis can be revolved to generate a 3D model (Fig. 6.4.14). The user first draws an axis and a profile, and then clicks on the 'Select' item to highlight it. He/she next selects the desired axis and profile. Last, the user clicks on the 'Revolve' item to create the 3D model. An important feature of the geometric modeling application is that the distance of the extrusion can be modified after the user conducts the extrusion. The user first clicks on the 'Select Extrusion' item to highlight it, and then picks an edge along the extrusive direction. The user next clicks on the 'Modify' item to change the current extrusive distance.

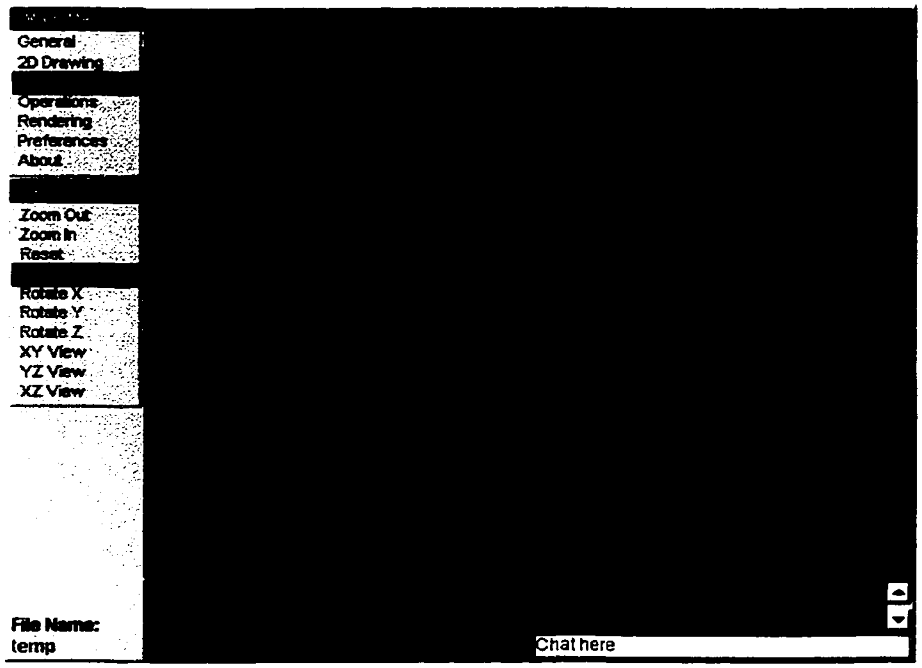


Fig. 6.4.14 3D Model Generated by Revolution Operation

There is no sub-level menu item under the ‘Rendering’ item in the main menu window. If the user clicks on the 'Rendering' item, a window pops up that describes the rendering strategy used in the geometric modeling application. Rendering is performed by the Java applet (Fig. 6.4.4), which works as follows. The user selects the desired shared file name. The Java applet then downloads the data file from the server and displays it in a true 3D perspective. Geometric data is converted into an internal representation of Java 3D for rendering. The Shockwave simulation continuously updates the geometric data file on the server. The Java applet monitors any change made to the file. If a change occurs, the Java applet automatically downloads the modified data file and redisplays it in the Java applet. A corresponding Java multi-user server works simultaneously with the Java applet. If one user rotates the model, other users can see the action and simultaneously obtain the same view of the model. The color of the displayed geometric model can be modified, and any change to the color propagates to other users' applets. The interface design of Java applet is easier than that of the Shockwave simulation because Java provides standard interface-related classes. In addition, the functions of this applet are relatively simple, because its main task is to render 3D geometric models. It consists of two areas: 1) button and message area, and 2) working area. Figure 6.4.15 illustrates the message and button area of the applet.

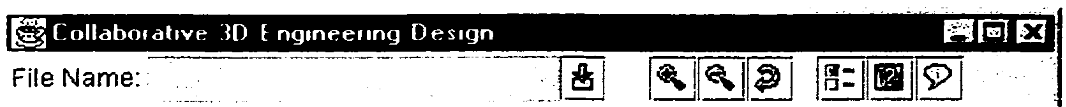


Fig. 6.4.15 Interface for Java Applet of the Geometric Modeling Application

Similarly, there is no sub-level menu item under the 'Preferences' and 'About' items in the main menu window. If the user clicks on the 'Preferences' item, a window pops up to let the user specify preferences (Fig. 6.3.16). There are three types of preferences. The view volume should be specified based on the actual dimensions of the model. It also determines the definition coordinate system. The zoom ratio controls the behaviors of zooming operations. The next six parameters define the location of the definition space in the world coordinate system. If the user clicks on the 'About' item, a window pops up to show the author information of the application.

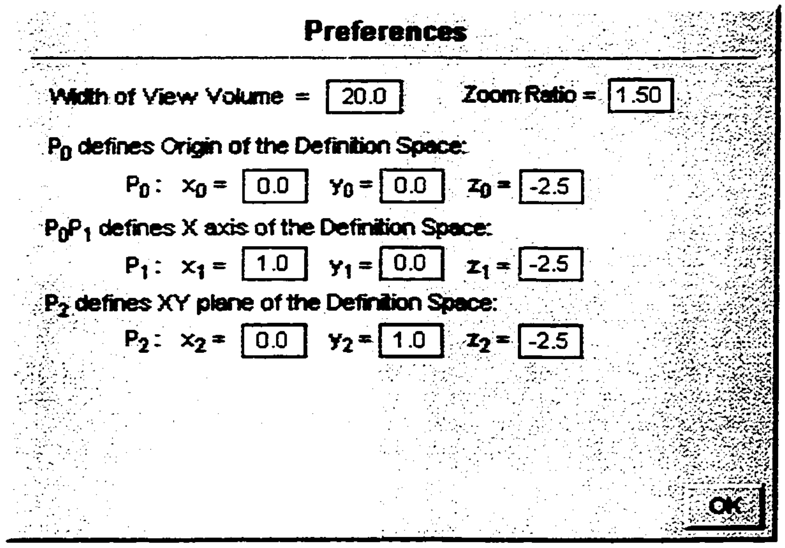


Fig. 6.4.16 Preference Window

6.4.4 Uniqueness

A number of unique features can be found in this distributed collaborative geometric modeling module. It is a complex application that smoothly integrates numerous Internet technologies, such as Java, Java 3D, Shockwave, ASP, SQL, VRML, Perl, and the database. It is the first collaborative geometric modeling tool for engineering education. Its collaborative capability encourages team spirit. It was integrated seamlessly with the 3D virtual world by depositing the generated 3D geometric objects into the virtual world. The generated geometric objects can be retrieved and analyzed by the collaborative engineering analysis module.

Furthermore, its architecture is different from that of conventional collaborative geometric modeling applications. Conventional applications usually have a geometric modeling engine located on the server, and a client-side application is mainly used to display the model. The traffic between the server and client is usually high in such applications. However, in this research, the multi-user server only manages communication between team members, and the client-side application takes care of modeling. Due to the adoption of this architecture, the user can interact directly with the geometric model to accomplish a variety of operations such as selecting geometric entities. This architecture also minimizes network traffic, because there is no need to download the geometric model after each operation.

A few unique programming techniques were employed in the development of the module. The object-oriented concepts were used extensively to integrate the vector-based graphic techniques. This significantly increases the readability of the codes. Standard stack data structures were simulated by the list data structures of Lingo. Using stacks efficiently solves the management problem of the channels.

6.4.5 Design Examples

Since the collaborative geometric modeling module is a prototype, not a general-purpose commercial program, its capability is limited. Despite this, it can still be used to design useful geometric objects and is excellent for engineering education. Figures 6.4.17, 6.4.18 and 6.4.19 show an example of bolt design utilizing the geometric modeling application. Figures 6.4.20 and 6.4.21 demonstrate an L bracket. Figures 6.4.22 and 6.4.23 illustrate a clip.

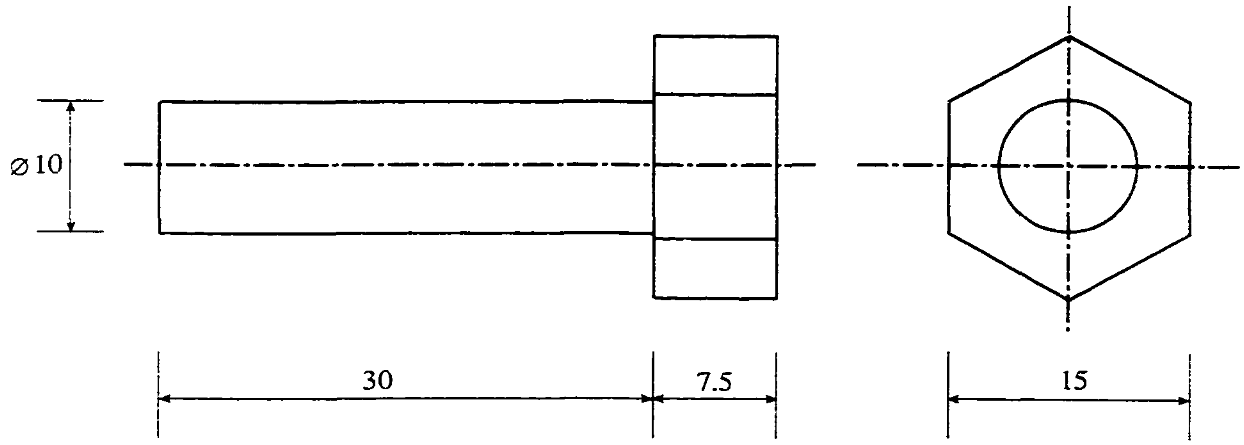


Fig. 6.4.17 Dimensions for the Bolt

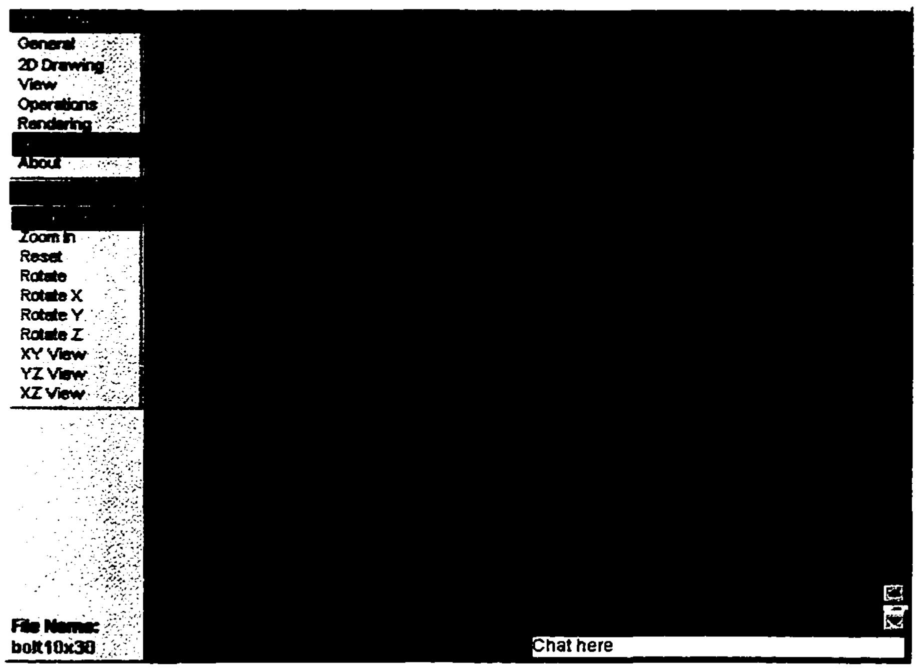


Fig. 6.4.18 Bolt in Wireframe

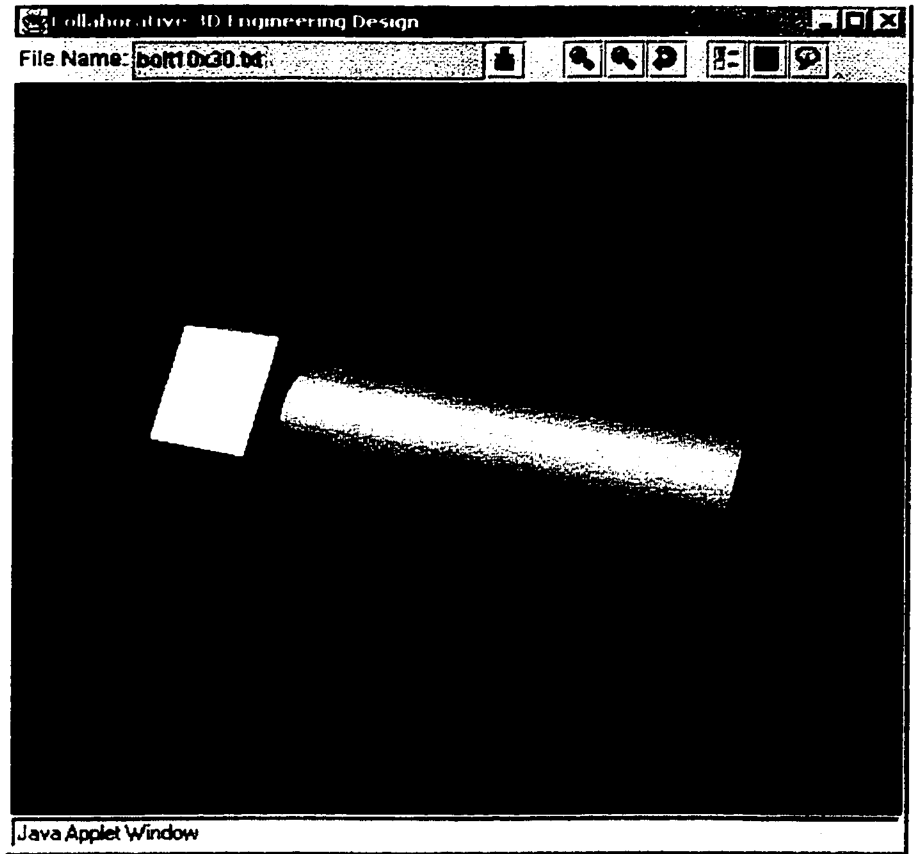


Fig. 6.4.19 Shaded Bolt

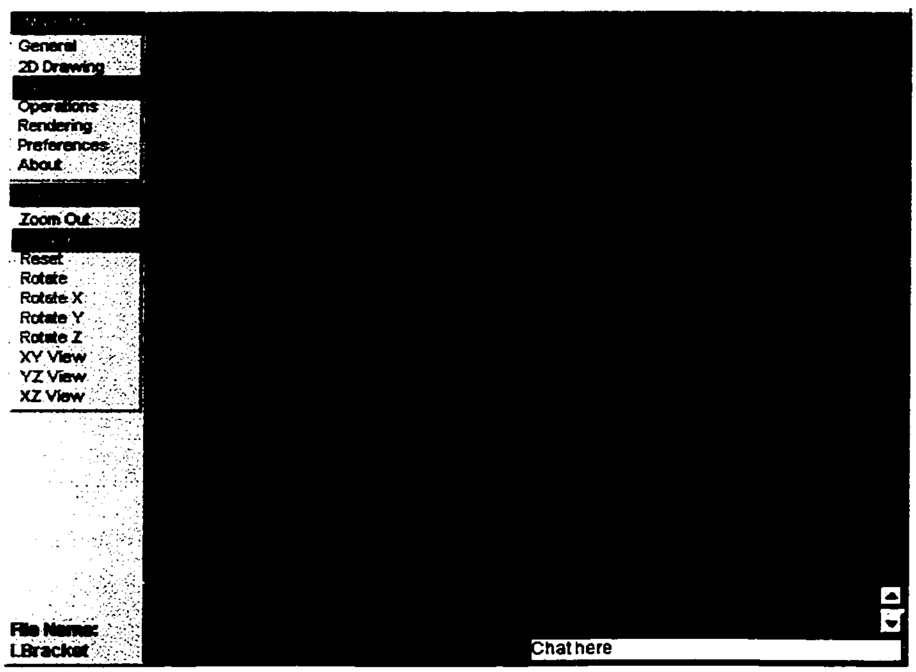


Fig. 6.4.20 Bracket in Wireframe

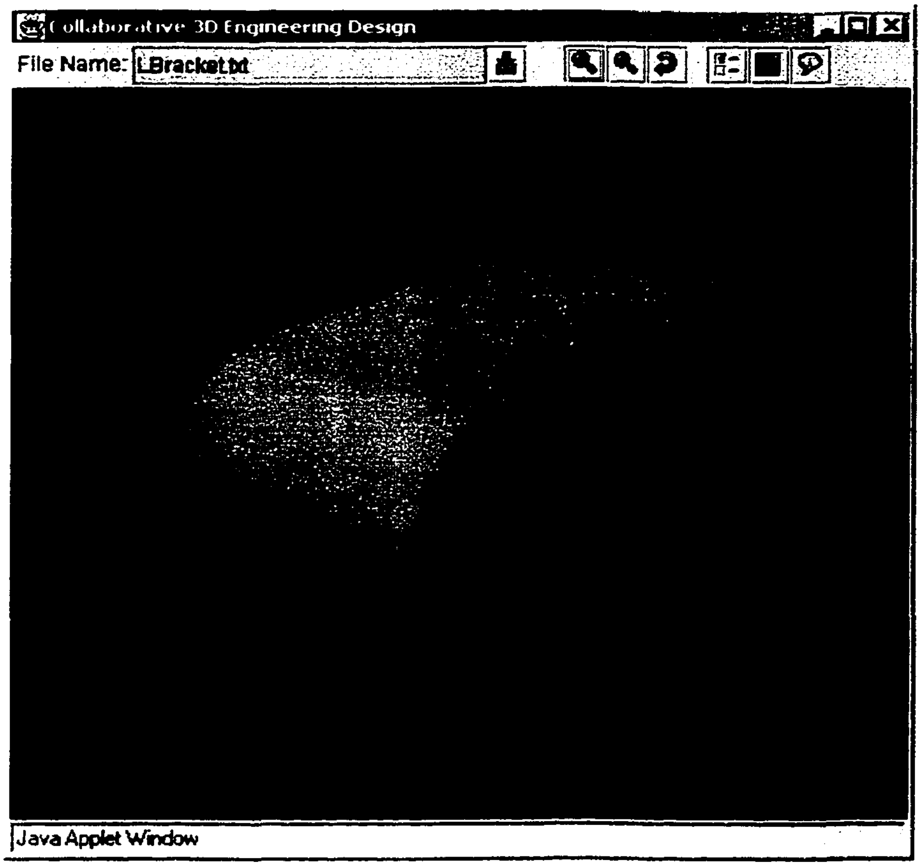


Fig. 6.4.21 Shaded Bracket

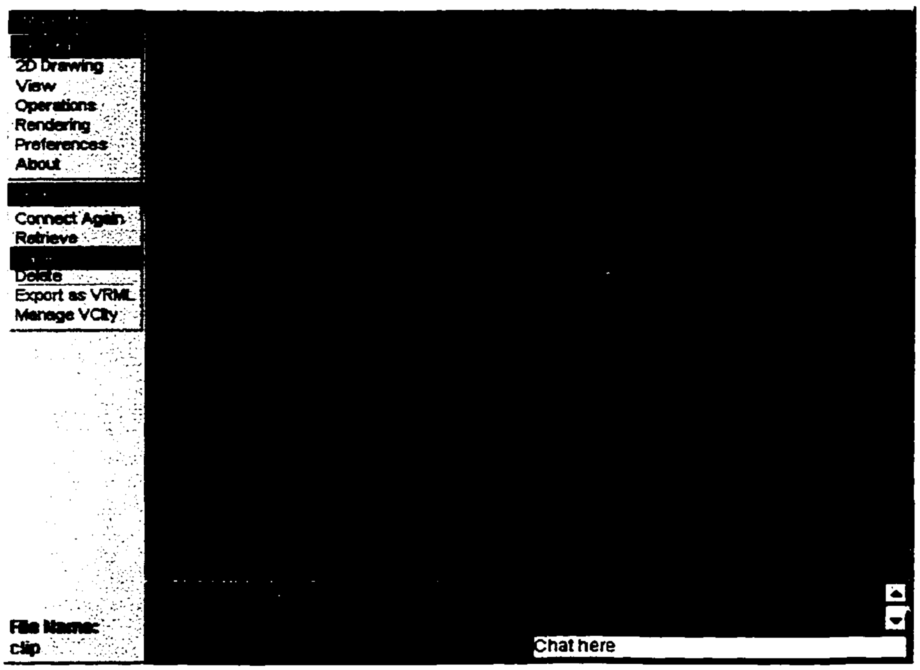


Fig. 6.4.22 Clip in Wireframe

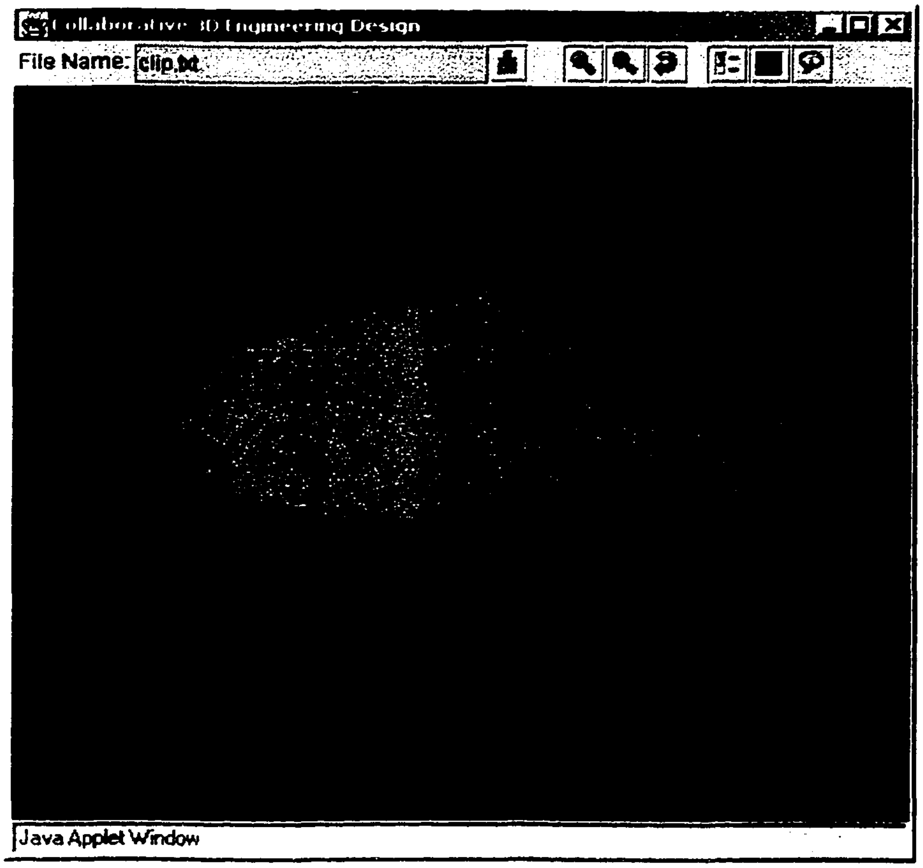


Fig. 6.4.23 Shaded Clip

6.5 Distributed Collaborative Engineering Analysis

6.5.1 Introduction

The engineering analysis module is the first environment that can conduct 3D finite element analysis collaboratively over the Internet. The engineering analysis module contains two components. One is a client-side applet (Fig. 6.5.1), which is used to conduct finite element analysis (Appendix F), and the other is a Java-based multi-user server, which manages communication and is the same multi-user server utilized in the geometric modeling module. Employing the same multi-user server can reduce the number of programs and hence minimize programming and managing tasks.

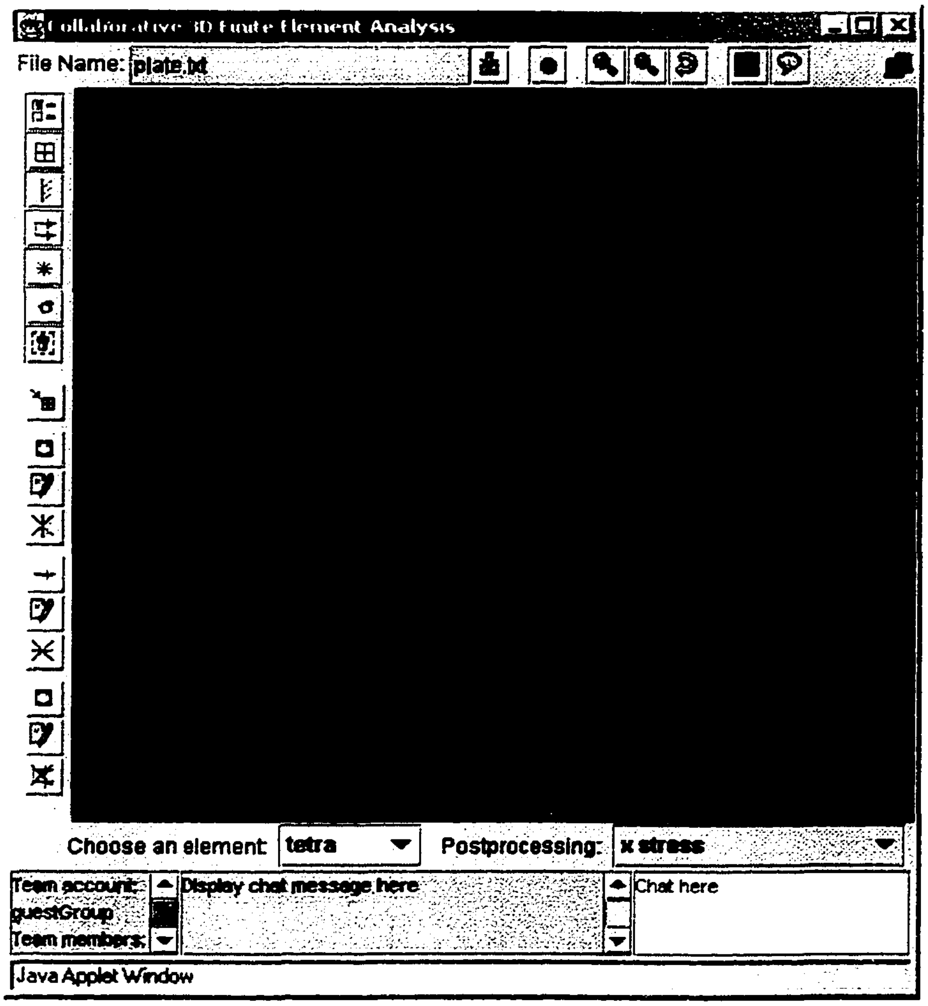


Fig. 6.5.1 Client-side Applet for Engineering Analysis

Currently, two types of elements: tetrahedral elements and hexahedral elements have been implemented. These two elements are the most common elements in 3D finite element analysis. Java and Java 3D were chosen to develop the engineering analysis module, because they provide excellent performance, support networking and 3D, and can be downloaded safely to run on client machines.

6.5.2 Tetrahedral Elements

Any structure is essentially a 3D model, although there are numerous simplified models such as rod, beam, plane stress, and plane strain elements. It is necessary to develop 3D elements for finite element analysis. The tetrahedron is the basic 3D element, and may be four-node, eight-node, ten-node, or twenty-node. Among them, four-node tetrahedral elements are the simplest and were chosen for designing the engineering analysis module (Fig. 6.5.2). The linear shape functions were employed to develop the stiffness matrices in terms of a global coordinate system. Detailed discussions about the development of stiffness matrices and the assembly of the global stiffness matrix can be found in numerous references [94, 95, 96].

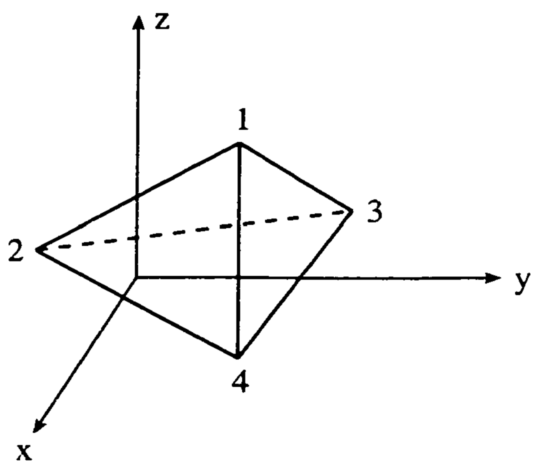


Fig. 6.5.2 Tetrahedral Element

6.5.3 Hexahedral Elements

In addition to tetrahedral elements, eight-node hexahedral elements were also implemented in the engineering analysis module. To derive the isoparametric formulation of the stiffness matrix for eight-node linear hexahedral elements, an isoparametric coordinate system is used as shown in Fig. 6.5.3. The element faces are then defined by $s,\ t,\ z' = \pm 1$.

The shape functions are defined as

$$N_i = \frac{(1 + ss_i)(1 + tt_i)(1 + z'z'_i)}{8} \tag{6.5.1}$$

with $s_i,\ t_i,\ z'_i = \pm 1$ and $i = 1,\ 2,\ ...,\ 8$.

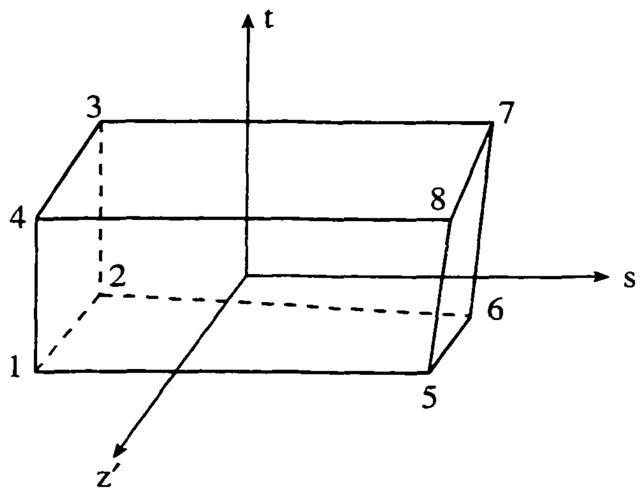


Fig. 6.5.3 Linear Hexahedral Element

Expanding the above equation, the following equations can be obtained

$$
\begin{aligned}
N_1 &= \frac{(1-s)(1-t)(1+z')}{8} && (-1,-1,1) \\
N_2 &= \frac{(1-s)(1-t)(1-z')}{8} && (-1,-1,-1) \\
N_3 &= \frac{(1-s)(1+t)(1-z')}{8} && (-1,1,-1) \\
N_4 &= \frac{(1-s)(1+t)(1+z')}{8} && (-1,1,1) \\
N_5 &= \frac{(1+s)(1-t)(1+z')}{8} && (1,-1,1) \\
N_6 &= \frac{(1+s)(1-t)(1-z')}{8} && (1,-1,-1) \\
N_7 &= \frac{(1+s)(1+t)(1-z')}{8} && (1,1,-1) \\
N_8 &= \frac{(1+s)(1+t)(1+z')}{8} && (1,1,1)
\end{aligned}
\qquad (6.5.2)
$$

These shape functions will now be used to map the solid block in isoparametric coordinates s, t, and z' to the block of x, y, and z coordinates whose size and shape are determined by the twenty-four nodal coordinates (x_1, y_1, z_1), ..., (x_8, y_8, z_8). The mapping functions are derived as follows,

$$
\begin{Bmatrix} x \\ y \\ z \end{Bmatrix} = \begin{bmatrix} N_1 & 0 & 0 & \cdots & N_8 & 0 & 0 \\ 0 & N_1 & 0 & \cdots & 0 & N_8 & 0 \\ 0 & 0 & N_1 & \cdots & 0 & 0 & N_8 \end{bmatrix}_{3\times 24} \begin{Bmatrix} x_1 \\ y_1 \\ z_1 \\ \cdots \\ x_8 \\ y_8 \\ z_8 \end{Bmatrix}_{24\times 1} \qquad (6.5.3)
$$

Assume that u, v, and w are the displacements along the x, y, and z axes. Based on the theory of linear elasticity, the strain/displacement relationships are

$$\begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \varepsilon_z \\ \gamma_{xy} \\ \gamma_{yz} \\ \gamma_{zx} \end{Bmatrix} = \begin{bmatrix} \frac{\partial()}{\partial x} & 0 & 0 \\ 0 & \frac{\partial()}{\partial y} & 0 \\ 0 & 0 & \frac{\partial()}{\partial z} \\ \frac{\partial()}{\partial y} & \frac{\partial()}{\partial x} & 0 \\ 0 & \frac{\partial()}{\partial z} & \frac{\partial()}{\partial y} \\ \frac{\partial()}{\partial z} & 0 & \frac{\partial()}{\partial x} \end{bmatrix} \begin{Bmatrix} u \\ v \\ w \end{Bmatrix} \tag{6.5.4}$$

The displacement functions within an element are now defined by the same shape functions as used to define the element shape; that is,

$$\begin{Bmatrix} u \\ v \\ w \end{Bmatrix} = \begin{bmatrix} N_1 & 0 & 0 & \cdots & N_8 & 0 & 0 \\ 0 & N_1 & 0 & \cdots & 0 & N_8 & 0 \\ 0 & 0 & N_1 & \cdots & 0 & 0 & N_8 \end{bmatrix}_{3\times 24} \begin{Bmatrix} u_1 \\ v_1 \\ w_1 \\ \cdots \\ u_8 \\ v_8 \\ w_8 \end{Bmatrix}_{24\times 1} \tag{6.5.5}$$

Equation 6.54 and 6.5.5 can be combined to obtain the following equation,

$$\begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \varepsilon_z \\ \gamma_{xy} \\ \gamma_{yz} \\ \gamma_{zx} \end{Bmatrix} = [B]_{6\times 24} \begin{Bmatrix} u_1 \\ v_1 \\ w_1 \\ \cdots \\ u_8 \\ v_8 \\ w_8 \end{Bmatrix}_{24\times 1} \tag{6.5.6}$$

where

$$
[B]_{6\times24} = \begin{bmatrix} \frac{\partial()}{\partial x} & 0 & 0 \\ 0 & \frac{\partial()}{\partial y} & 0 \\ 0 & 0 & \frac{\partial()}{\partial z} \\ \frac{\partial()}{\partial y} & \frac{\partial()}{\partial x} & 0 \\ 0 & \frac{\partial()}{\partial z} & \frac{\partial()}{\partial y} \\ \frac{\partial()}{\partial z} & 0 & \frac{\partial()}{\partial x} \end{bmatrix}_{6\times3} \begin{bmatrix} N_1 & 0 & 0 & \cdots & N_8 & 0 & 0 \\ 0 & N_1 & 0 & \cdots & 0 & N_8 & 0 \\ 0 & 0 & N_1 & \cdots & 0 & 0 & N_8 \end{bmatrix}_{3\times24} \tag{6.5.7}
$$

Also, [B] matrix can be written in the following form,

$$
[B] = [B_1 \quad B_2 \quad B_3 \quad B_4 \quad B_5 \quad B_6 \quad B_7 \quad B_8] \tag{6.5.8}
$$

The submatrix $B_i\,(i = 1, \ldots, 8)$ is defined by

$$
B_i = \begin{bmatrix} \frac{\partial N_i}{\partial x} & 0 & 0 \\ 0 & \frac{\partial N_i}{\partial y} & 0 \\ 0 & 0 & \frac{\partial N_i}{\partial z} \\ \frac{\partial N_i}{\partial y} & \frac{\partial N_i}{\partial x} & 0 \\ 0 & \frac{\partial N_i}{\partial z} & \frac{\partial N_i}{\partial y} \\ \frac{\partial N_i}{\partial z} & 0 & \frac{\partial N_i}{\partial x} \end{bmatrix} \tag{6.5.9}
$$

To compute $\frac{\partial N_i}{\partial x}, \frac{\partial N_i}{\partial y}, \frac{\partial N_i}{\partial z} (i = 1, \ldots, 8)$, the following equations can be used,

$$\frac{\partial N_i}{\partial x} = \frac{\begin{vmatrix} \frac{\partial N_i}{\partial s} & \frac{\partial y}{\partial s} & \frac{\partial z}{\partial s} \\ \frac{\partial N_i}{\partial t} & \frac{\partial y}{\partial t} & \frac{\partial z}{\partial t} \\ \frac{\partial N_i}{\partial z'} & \frac{\partial y}{\partial z'} & \frac{\partial z}{\partial z'} \end{vmatrix}}{|J|} \tag{6.5.10}$$

$$\frac{\partial N_i}{\partial y} = \frac{\begin{vmatrix} \frac{\partial x}{\partial s} & \frac{\partial N_i}{\partial s} & \frac{\partial z}{\partial s} \\ \frac{\partial x}{\partial t} & \frac{\partial N_i}{\partial t} & \frac{\partial z}{\partial t} \\ \frac{\partial x}{\partial z'} & \frac{\partial N_i}{\partial z'} & \frac{\partial z}{\partial z'} \end{vmatrix}}{|J|} \tag{6.5.11}$$

$$\frac{\partial N_i}{\partial z} = \frac{\begin{vmatrix} \frac{\partial x}{\partial s} & \frac{\partial y}{\partial s} & \frac{\partial N_i}{\partial s} \\ \frac{\partial x}{\partial t} & \frac{\partial y}{\partial t} & \frac{\partial N_i}{\partial t} \\ \frac{\partial x}{\partial z'} & \frac{\partial y}{\partial z'} & \frac{\partial N_i}{\partial z'} \end{vmatrix}}{|J|} \tag{6.5.12}$$

where $i = 1, \ldots, 8$ and

$$|J| = \begin{vmatrix} \frac{\partial x}{\partial s} & \frac{\partial y}{\partial s} & \frac{\partial z}{\partial s} \\ \frac{\partial y}{\partial t} & \frac{\partial y}{\partial t} & \frac{\partial z}{\partial t} \\ \frac{\partial z}{\partial z'} & \frac{\partial y}{\partial z'} & \frac{\partial z}{\partial z'} \end{vmatrix} \tag{6.5.13}$$

The 24×24 stiffness matrix is now given by

$$[k] = \int_{-1}^{1} \int_{-1}^{1} \int_{-1}^{1} [B]^T [D][B] |J| \, ds \, dt \, dz' \tag{6.5.14}$$

where [D] is defined by

$$\{\sigma\} = [D]\{\varepsilon\} \tag{6.5.15}$$

which is a system of equations for the stress/strain relationships. Details about [D] matrix can be found in the reference [94].

It is best to evaluate [k] by numerical integration. In this research, a $2\times2\times2$ rule (Gaussian quadrature) was used to evaluate the eight-node hexahedral element stiffness matrix. More details about the evaluation of [k] can be found in the reference [94]. After the local stiffness matrix [k] is computed, the global stiffness matrix can then be assembled.

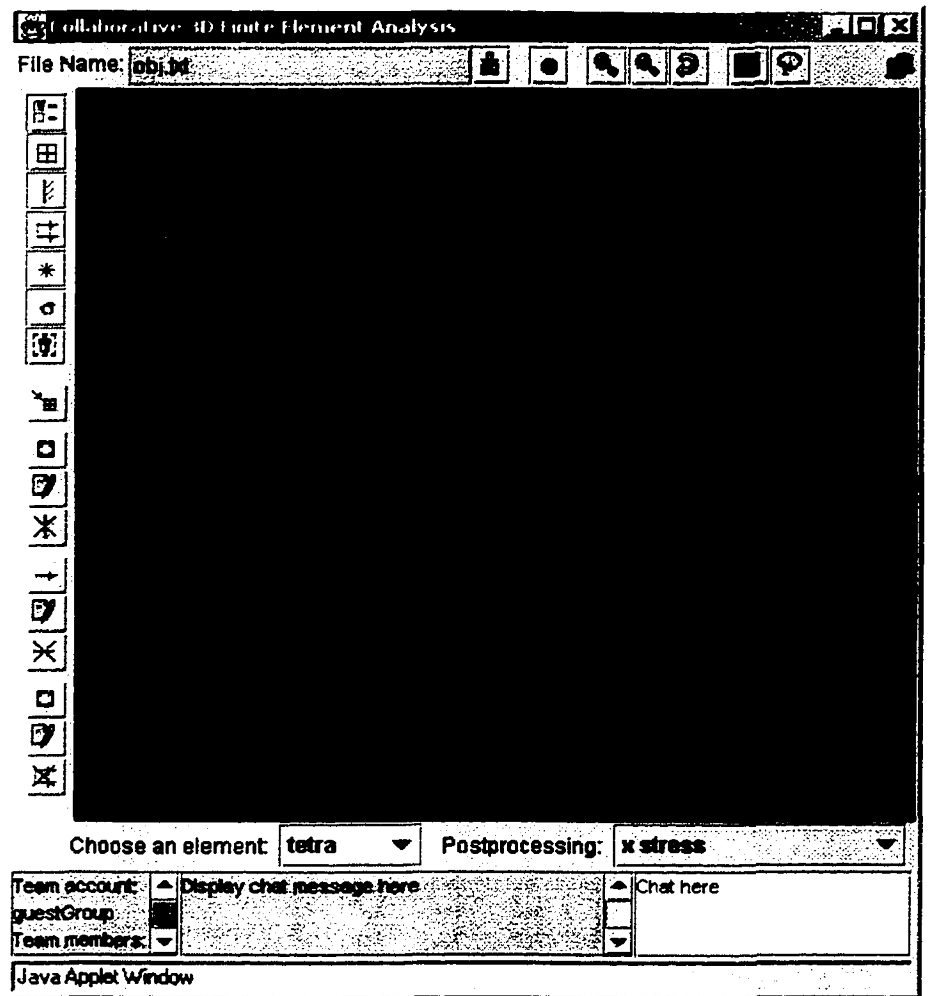


Fig. 6.5.4 Interface of the Engineering Analysis Application

6.5.4 Functions of the Engineering Analysis Application

It is always a challenge to design a user-friendly intuitive interface for finite element analysis. This is because finite element analysis is a complex procedure and demands that the user have an understanding of the problem, mechanics, theory, and limitations of the finite element method. The interfaces of commercial finite element codes are usually difficult to use, because their original interface design was historically based on X Windows of the UNIX operating system. Therefore, one of the primary goals of the engineering analysis application was to design a user-friendly interface. Buttons are grouped into three toolbars according to their functions: top toolbar, left toolbar, and bottom toolbar, as discussed further below (Fig. 6.5.4).

These three toolbars provide button-driven actions. In addition, the user can also employ the mouse to rotate, translate, and zoom in on or out from the object. For example, if the user clicks and drags the mouse, the user can rotate the object. This is particularly convenient, because these actions are not associated with any button.

6.5.4.1 Functions of the Top Toolbar

The top toolbar includes the buttons related to importing new files, connecting team members, zooming, and showing information. If the user clicks on the 'Import' button , a window pops up that lets the user select an available file from the file list (Fig. 6.5.5). The list is generated by a CGI program, which obtains the file names from the database. If the user clicks on the 'Enter' button, the selected file name shows up in the message area beside the 'Import' button. The 'Network' button  is consistent with the icon , which shows that the user is ready to share the analysis procedures with other members. However, if the user clicks on the 'Network' button, its image changes to and the icon becomes , which shows that user does not share any analysis procedure with other members. The next three buttons are the 'Zoom In' button , 'Zoom Out' button , and 'Reset' button . The user can clicks on these buttons to adjust the viewing distance to the model. The last two buttons in the top toolbar are the 'Help' button , and 'About' button . The user can use these two buttons to obtain the information about the application and author.

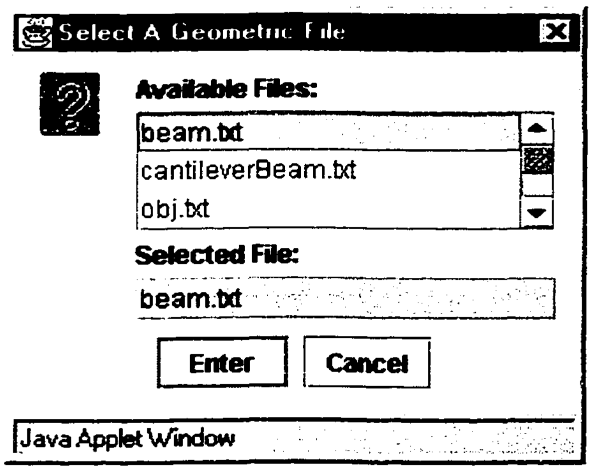


Fig. 6.5.5 Window for File Importing

6.5.4.2 Functions of the Left Toolbar

The left toolbar incorporates the buttons related to finite element analysis. Clicking on the first seven buttons creates immediate actions, such as the generation of meshes, computation, and creation of distributed forces and boundary conditions, as well as, the presentation of the report. Depressing the other buttons allows the user to take mouse actions, such as picking a quad, edge, force, or boundary condition.

6.5.4.2.1 Preferences

Before the user conducts finite element analysis, he/she should set the preferences. If the user clicks on the 'Preference' button , a window pops up (Fig. 6.5.6), which allows the user to select the unit and specify the material properties: elasticity modulus, and Poisson's ratio. If the user clicks on the 'Enter' button, the modified values will be recorded and used in the computational procedure. Only the isotropic elastic material is considered because the analysis application is a prototype.

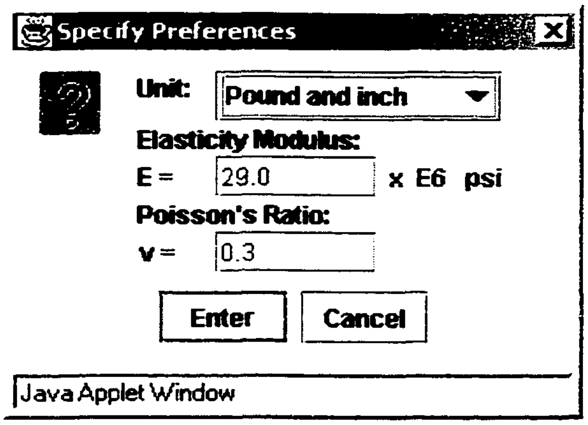


Fig. 6.5.6 Preference Window

6.5.4.2.2 Meshing

After the user imports a geometric model to the application, the next step is to mesh the model. However, it is particularly difficult to find a general meshing strategy for any geometric object, because the shape of actual geometric objects may be arbitrary. As the focus of this research is not on meshing strategies, a simple meshing approach was adopted to reduce the meshing workload (Fig. 6.5.4).

This meshing approach involves a few steps. First, the user depresses the 'Pick Edges for Meshing' button. Second, the user selects an arbitrary edge of the geometric object and a dialog window pops up (Fig. 6.5.7). The user then assigns the number of blocks to be associated with that edge. Third, the user chooses another edge that has a common vertex with the first edge selected and assigns the number of blocks to be associated with the second edge. Fourth, the user picks a third edge that shares a common vertex with the first two edges selected and assigns the number of blocks to be associated with the third edge. When these three values are ready, the geometric object can then be meshed into multiple eight-node blocks if the user clicks on the 'Mesh' button. The vertices of these blocks are automatically indexed. Figure 6.5.4 demonstrates the blocks generated by this meshing approach. The limitation of this approach is that it only works with geometric objects having six surfaces. If the geometric objects have more or less than six faces, this approach does not work.

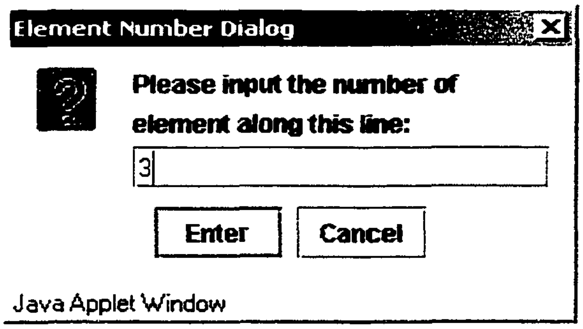


Fig. 6.5.7 Element Number Dialog Window

As these blocks can be used as the hexahedral elements, no further meshing is needed. For tetrahedral elements, it is necessary to further divide each block into five or six tetrahedra. In this research, each block was divided into six tetrahedral elements. Detailed discussions about division can be found in the reference [96].

When the meshing approach is available, it is crucial to find an efficient way to store the global stiffness matrix. This is important due to limitations in storage capacity. Assume that a meshed 3D object has 2000 nodes and that each element of the matrix requires two bytes for data storage. The meshed object may form a 6000×6000 global matrix, which needs 72 megabytes of memory to store it. Although more memory is available with current computers, it is still not enough to hold the uncompressed matrix, especially considering many more nodes may be needed for the analysis of complex 3D objects.

As the global matrix is symmetric and banded, a banded-symmetric format storage approach is used in this research. This format is not necessarily the most efficient format; however it is simple to implement. Using a banded-symmetric format, only the main diagonal and nonzero upper codiagonals need to be stored; hence, the number of stored elements is tremendously reduced. In addition to the storage efficiency, the equation-solution time with banded storage is also less than that required without banded storage [94].

The algorithm for solving linear equations with a banded-symmetric format is standard and can be found in numerous references [96, 97]. This research used the FORTRAN source code from the reference [96]. The FORTRAN code was converted into Java code.

6.5.4.2.3 Boundary Conditions

When the meshing is finished, it is necessary to apply boundary conditions. Below the button, the next three buttons are grouped to deal with boundary conditions. First, the user depresses the 'Pick Quads' button, and he/she then picks desired quads. The selected quads become green. Second, the user clicks on the 'Boundary Condition' button, and a window pops up to let the user specify the degrees of freedom for selected quads (Fig. 6.5.8). If the user chooses to clicks on the 'Enter' button, a colored block is placed on the top of the green quads to indicate that a boundary condition is applied on these quads. If the user wants to change the degree of freedom of the boundary condition, he/she can depress the 'Edit BC' button and then pick the colored block that represents the boundary condition. A window pops up to let the user modify the degrees of freedom. If the user decides to delete the generated boundary condition, he/she can depress the 'Delete BC' button, and then click on the desired colored block to delete it.

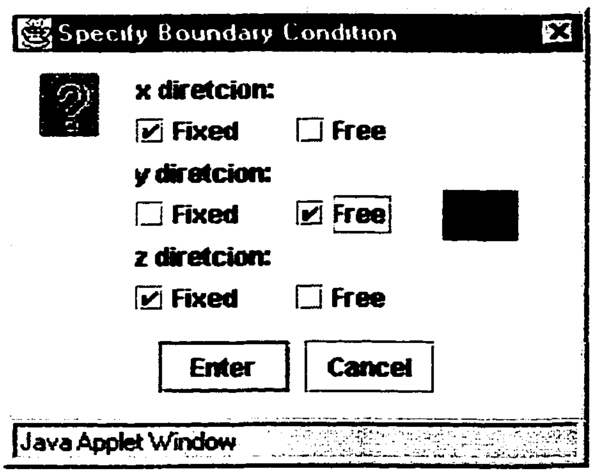


Fig. 6.5.8 Boundary Condition Window

6.5.4.2.4 Forces

Two types of forces can be applied in the analysis application: point forces and distributed forces. The user first depresses the 'Point Force' button, and then picks any node. A window pops up to let the user specify the value of point forces (Fig. 6.5.9). If the user clicks on the 'Enter' button, a point force is created with the direction specified by its three components. Likewise, the user can use the two buttons below the button to edit and delete the point force.

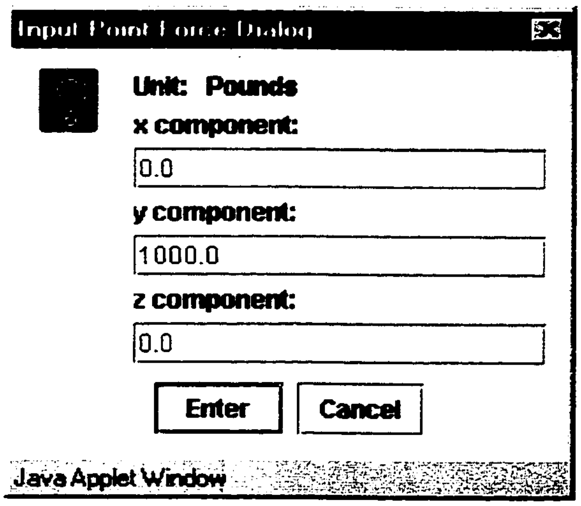


Fig. 6.5.9 Input Window for Point Forces

It is more complex to specify the distributed forces, and the procedure is similar to create the boundary condition. The user first depresses the 'Pick Quads' button, which is below the 'Delete Point Force' button, and then picks desired quads. The user next clicks on the 'Distributed Forces' button, and a window pops up to allow the user to define the direction and value of distributed force. If the user clicks on the 'Enter' button, the distributed force is generated, which is located in the middle of the quads. Similar to the point force, the user can edit or delete the distributed force.

6.5.4.2.5 Computation and Result Reports

After the meshes, boundary condition, and forces are ready, the user can click on the 'Compute' button to start the calculation. An interactive progress bar pops up, showing the computational progress and telling the user how much waiting time is necessary (Fig. 6.5.10). If the user clicks on the 'Delete All' button, all of the meshes, forces, boundary conditions, and results are deleted.

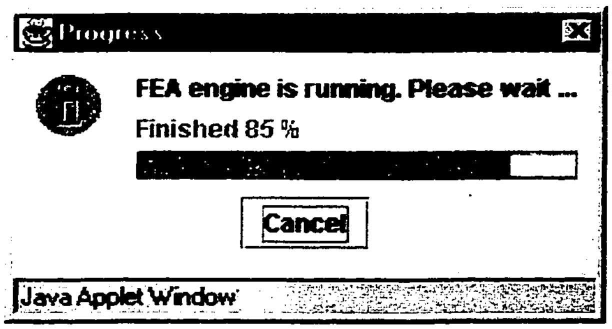


Fig. 6.5.10 Progress Bar

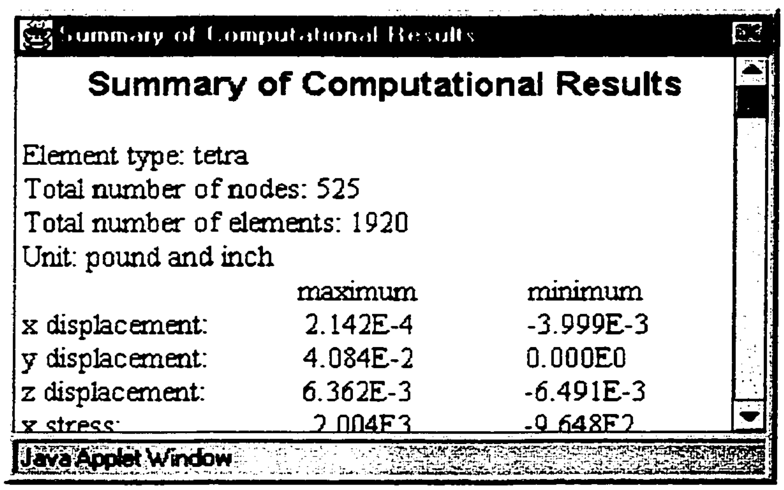


Fig. 6.5.11 Results Report

It is necessary to present and explain the results after the computation. This procedure is called post-processing, which is always a challenging task because it is difficult to present the results in a meaningful and easily understood way. Two approaches were adopted. The first approach is to provide a report on the results. The report presents basic information about the finite element analysis, such as element type, number of nodes, number of elements, units, and a summary of the stresses, shears, and displacements. If the user clicks on the 'Report' button , a resultant report is generated (Fig. 6.5.11). The second approach is discussed in the next section.

6.5.4.3 Functions of the Bottom Toolbar

The bottom toolbar groups two combo boxes and three text areas. The first combo box lets the user specify the element type, and the second combo box is for post-processing (Fig. 6.5.12). Using the combo box, the user can easily access options hidden in the box.

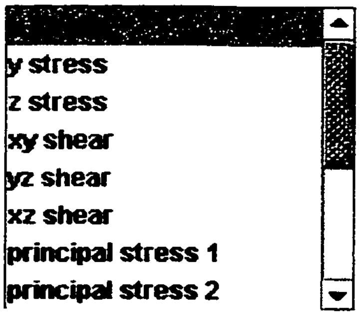


Fig. 6.5.12 Post-processing Combo Box

Two types of elements are supported in the first combo box: tetra elements and brick elements. Before the user start the computation, he/she can select the desired elements. In the second combo box, the user can choose different results to be displayed. This is the second approach for post-processing, which utilizes colors to demonstrate the stresses and displacements visually.

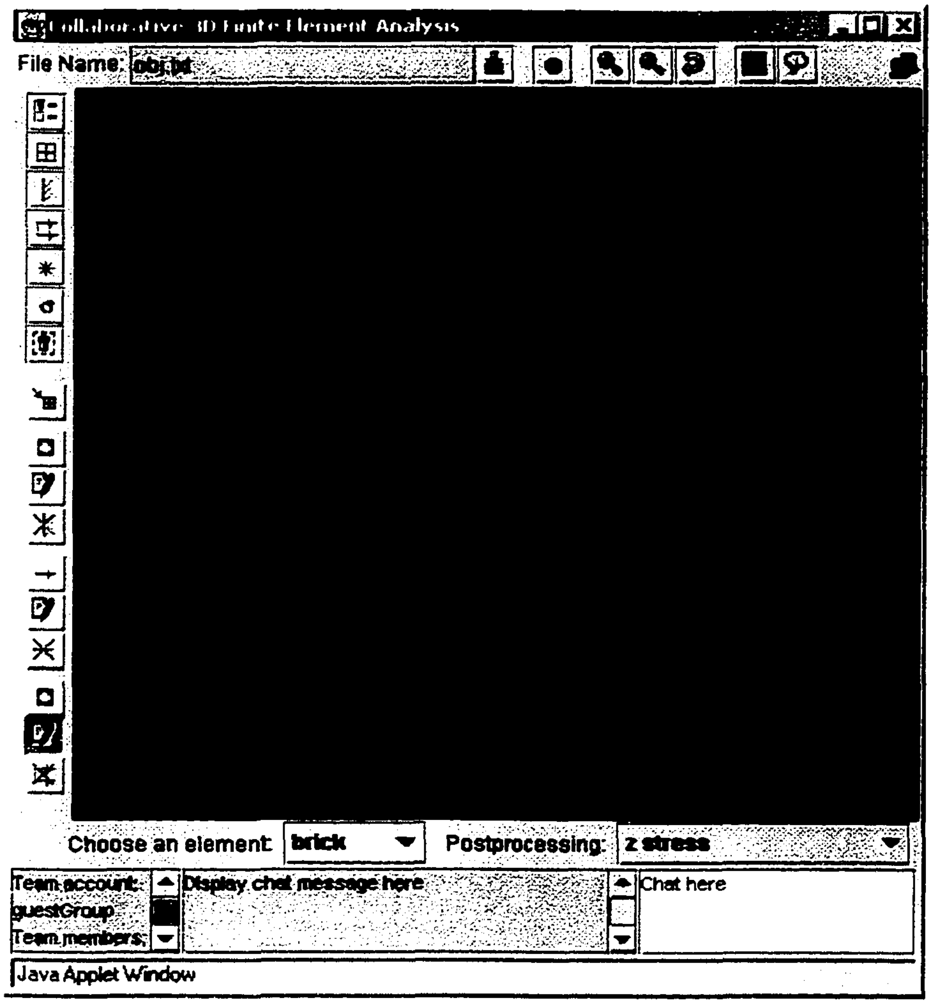


Fig. 6.5.13 Color Representation of z Stresses

The idea of the second approach for post-processing is simple. Assume that the z stress needs to be presented. First, the maximum z stress and minimum z stress are determined. Second, the nodes with the maximum z stress are assigned the color red, the nodes with the zero stress are assigned green, and the nodes with the minimum stress are assigned blue. Third, the nodes with a value of z stress between the maximum z stress and zero stress are interpolated to assign colors between red and green. Similarly, if the minimum stress is less than zero, the nodes with a value of z stress between the zero stress and the minimum stress are interpolated to assign colors between green and blue. In this way, the regions with high z stresses and low z stresses can be found easily. Meanwhile, a colored block is used to show the colors representing the maximum stress, minimum stress, and zero stress. Figure 6.5.13 illustrates the use of the colors to represent z stresses. In addition to the normal stresses, shearing stresses, and displacements, the principal stresses, von Mises stresses, and absolute shearing stresses are presented visually as well. The definitions of these stresses can be found in the references [96, 98].

The text areas are for displaying current user information and chat messages. The right text area with white background color is for typing. The middle text area with light background color is a message board for displaying text from all users. The left text area is used to display the information associated with the team account and current team members.

6.5.5 Design of Internet-based Distributed Collaboration

In addition to the theory and implementation of the finite element method, the design of Internet-based distributed collaboration also plays a vital role in the engineering analysis module. This is because the module is not a stand-alone application; rather, it is an application with communication capabilities. The general communication strategy is to share actions between geographically dispersed users. These actions include importing geometric files, meshing the objects, applying boundary conditions and forces, conducting computation, rotating the objects, zooming in on or zooming out from the objects, and viewing the results. When a user initiates one of the actions, that action will be propagated to the remote users. Therefore, all of the remote users in the same working team will have the same results, same view, and same object.

To design an efficient application with distributed collaboration, numerous situations need to be considered. First, the finite element method has to deal with a large amount of data. Thus, only the action commands are shared, not the generated data. The generated data are usually a large amount, while the data for commands are small. This method can minimize the data that need to be transmitted through the Internet; hence it reduces the traffic imposed on the Internet and increases the responsiveness of the environment.

Second, multiple copies of information may be sent to the new user when the existing users detect the 'join' action. To avoid this, a unique token is used for the working team. If one user is holding the token, other users cannot hold it. Therefore, only the user holding the token can send a copy of information to the new user. Other users have to ignore the join action even though they have detected it.

Third, a user may leave the working team and rejoin it again. When the user leaves the working team, that person does not send or receive any message from other users. The individual can work independently on geometric objects. However, if the person decides to rejoin the working team, their objects will be lost when he receives the current copy of the working object from the team. This is important, because only one copy of information can exist within the team.

Fourth, each user may create new objects, such as boundary conditions and forces. These new objects can be easily identified in the creator's local machine, though not in the remote users' machines. To solve this problem, a globally unique ID is assigned to the generated object by the creator's machine and then propagated to the object generated by remote user's machines. Hence the generated object in each machine has the same unique ID. When the user needs to edit or delete the generated objects, the unique IDs are used to distinguish objects.

Fifth, it is important to find a consistent and convenient approach to retrieve data due to the large amount of data transmitted through the Internet. Object serialization is an excellent solution where the sender encapsulates the data into a serializable object and sends it. The receiver gets the serializable object and casts it back to the original object. The receiver can then retrieve the data. This is particularly convenient, because the data items have names associated with them. Shockwave implementation is different from this approach because it sends an array instead of a serializable object. The receiver needs to follow the precise order of the array to retrieve the data items. No name is associated with the data item in Shockwave multi-user implementation, which makes programming more difficult.

6.5.6 Comparison of Computational Results

It is important to assess whether the results obtained from the engineering analysis module agree with the results from commercial codes as well as with analytical results. Assume there is a beam of $10\times10\times100$ inches (Fig. 6.5.14). One end is fixed, and a 2000 lb point force is applied to the other. The elastic modulus is 29.0E6 psi and the Poison ratio is 0.3.

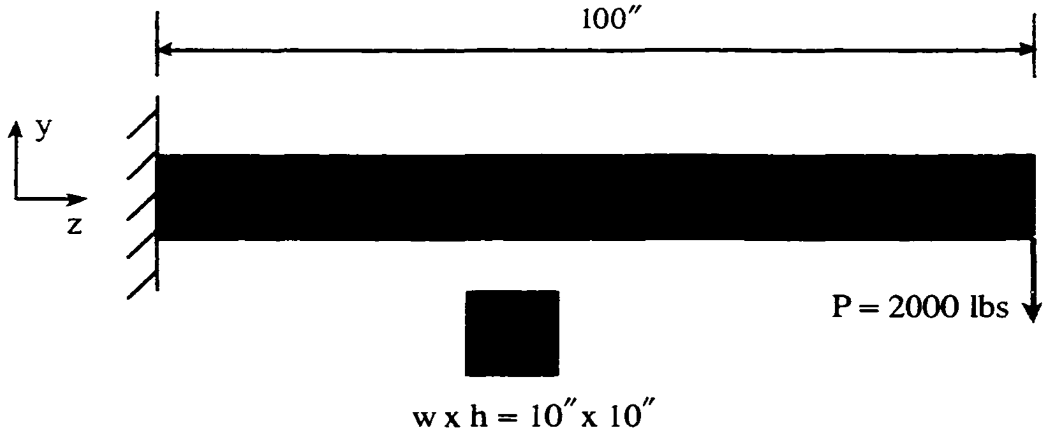


Fig. 6.5.14 A Beam Example Used to Check the Results

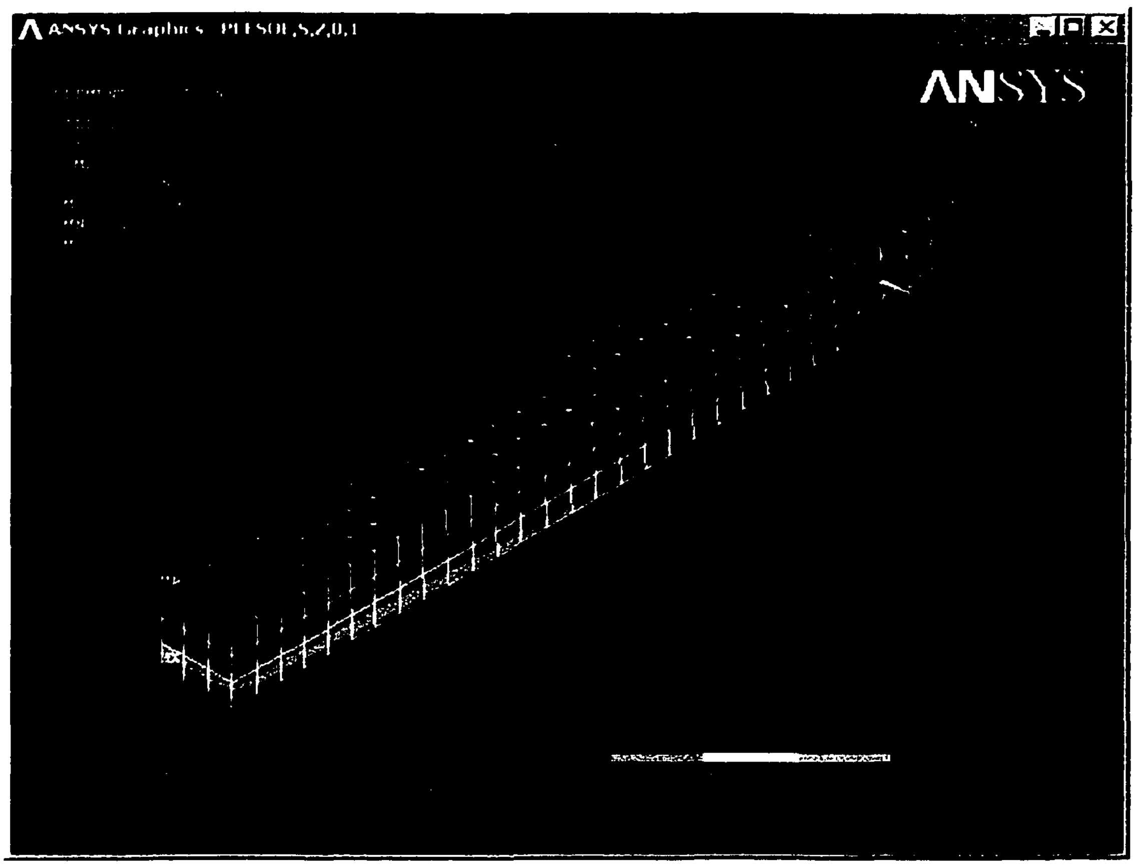


Fig. 6.5.15 Stress Results Using Brick Elements in ANSYS

If 270 brick elements with 496 nodes are used to analyze the beam in the engineering analysis module, the maximum displacement is 0.02591 inch and the maximum stress in z direction is 1396.0 psi. When the same number of elements and same meshing strategy are used to perform analysis on the beam in ANSYS, the maximum displacement is 0.02595 and the maximum stress in z direction is 1398.0 psi (Fig. 6.5.15). The difference between the maximum displacements is 0.15%, which is small. The difference between the maximum stresses in z direction is 0.14%, which is also at an acceptable level.

If 1620 tetra elements with 496 nodes are used in the engineering analysis module, the maximum displacement is 0.01947 inch and the maximum stress in z direction is 1165.0 psi. While 1646 tetra elements with 509 nodes are used to perform analysis on the beam in ANSYS, the maximum displacement is 0.02108 inch and the maximum stress in z direction is 1234.0 psi (Fig. 6.5.16). The difference between the maximum displacements is 7.63%, and the difference between the maximum z stresses is 5.59%. The differences are larger than using brick elements because the meshing strategy and number of elements are not the same.

Based on the classic beam theory, the maximum displacement in y direction is 0.02758 inch and the compression stress component along the beam is 1200.0 psi. The results computed from tetra elements are not as accurate as those from brick elements. This agrees with basic principles of finite element analysis. In summary, the results obtained from the collaborative engineering analysis agree with the results from commercial codes as well as with analytical results.

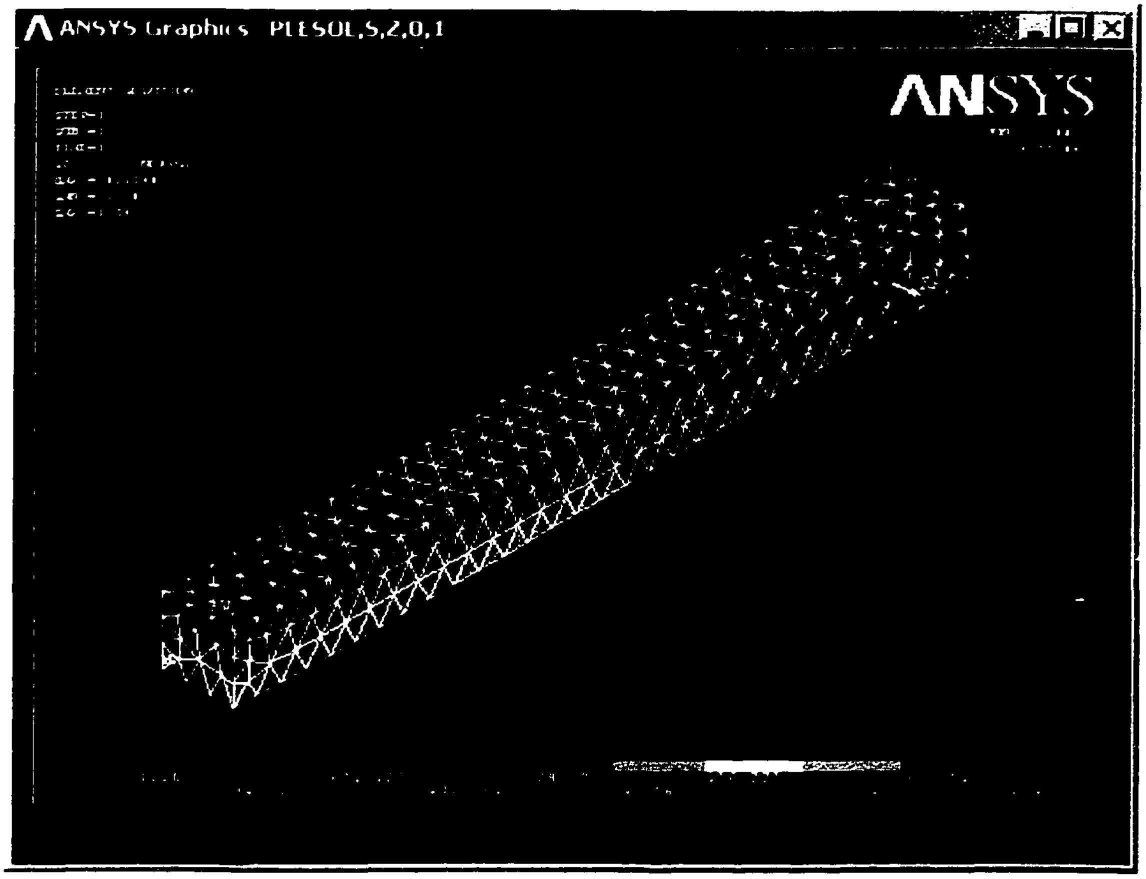


Fig. 6.5.16 Stress Results Using Tetra Elements in ANSYS

6.5.7 Uniqueness

The collaborative engineering analysis module has numerous unique features. It is the first prototype of the Internet-based distributed collaborative environment for 3D finite element analysis. It allows users to work collaboratively on the same analysis object simultaneously. It reads the geometric data from the collaborative geometric modeling and then seamlessly links both applications together. The user can interact directly with the geometric model to perform operations, such as applying, editing, and deleting boundary conditions and forces. The team members share operation commands instead of results so that the network traffic associated with collaboration is minimized. A database is utilized to manage the geometric files used in the engineering analysis, which is efficient.

6.5.8 An Analysis Example

As the distributed collaborative engineering analysis is a prototype, not a general-purpose commercial FEA program, its capability is rather limited. However, it is an excellent tool for engineering education. It can be downloaded and run on the client machine without installation.

As an example, a retaining wall under the distributed force was analyzed using this application. Figure 6.5.17 shows the boundary conditions and applied forces of the retaining wall. Figure 6.5.18 demonstrates the meshing of the wall. The maximum von Mises stress is 79.52 psi, and absolute maximum shear stress is 45.52 psi (Fig. 6.5.19).

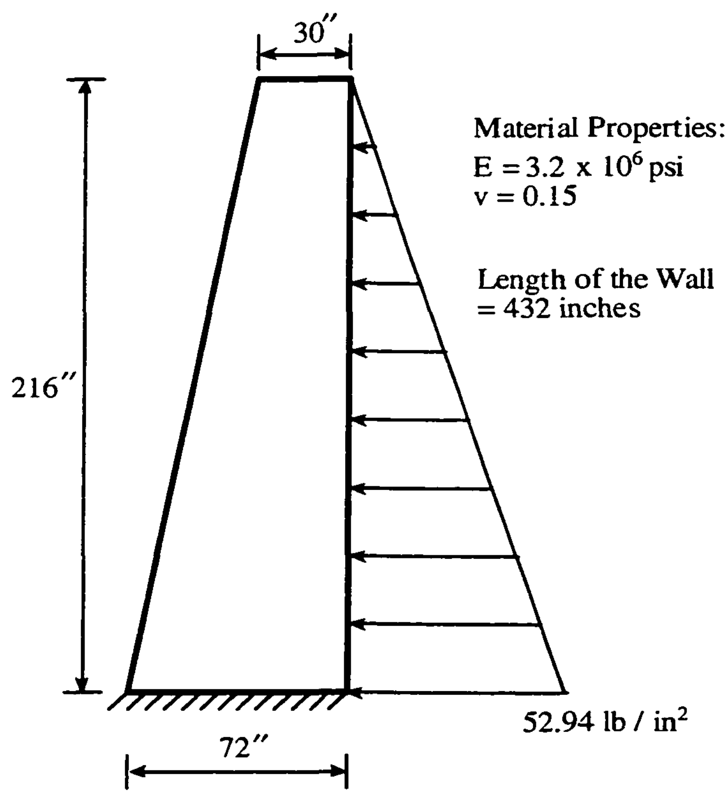


Fig. 6.5.17 Retaining Wall with Boundary Conditions and Forces

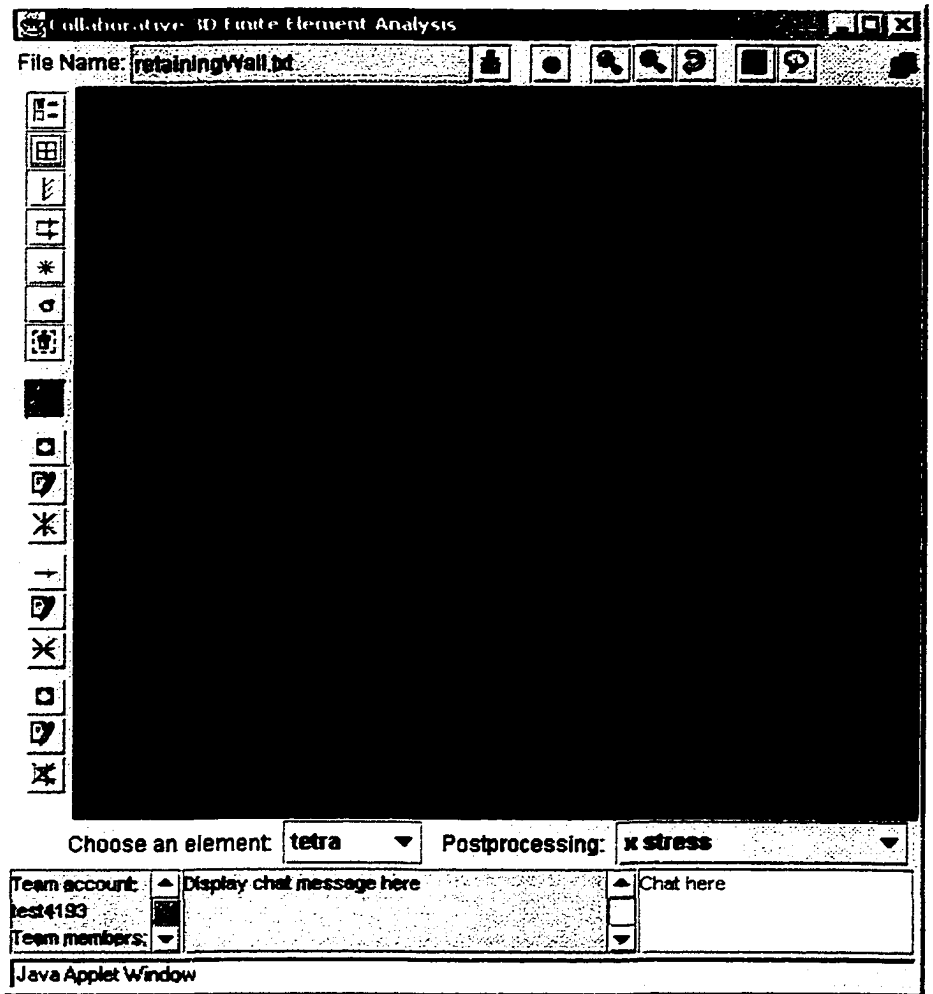
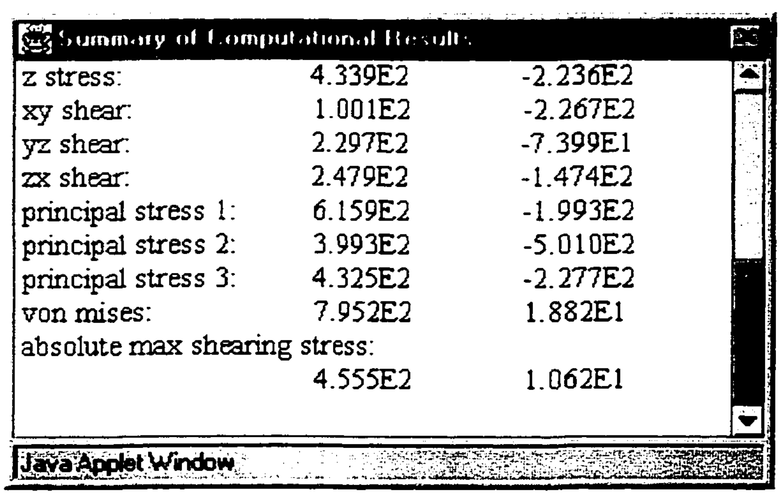


Fig. 6.5.18 Meshes of the Retaining Wall



z stress:	4.339E2	-2.236E2
xy shear:	1.001E2	-2.267E2
yz shear:	2.297E2	-7.399E1
zx shear:	2.479E2	-1.474E2
principal stress 1:	6.159E2	-1.993E2
principal stress 2:	3.993E2	-5.010E2
principal stress 3:	4.325E2	-2.277E2
von mises:	7.952E2	1.882E1
absolute max shearing stress:		
	4.555E2	1.062E1

Java Applet Window

Fig. 6.5.19 Summary of the Computational Results

Chapter 7: Assessment

Because the Virtual City is intended in part for engineering education, it is important to evaluate its effectiveness. Students were first required to finish an assignment using the Virtual City, and then they were asked to complete a survey about the effectiveness of the Virtual City. Three assessments were conducted as described below, and the results were analyzed statistically.

7.1 Assessments on the Multimedia Modules

7.1.1 Assessment on the Traffic Engineering Module

The first assessment was conducted on the effectiveness of the traffic engineering module at the University of Oklahoma in the fall of 1998. As a precursor to a corridor design, students were given the module and traffic flow volume. They were asked to design a freeway section with an acceptable level of service by adjusting the number of lanes and acceleration lengths. They were to learn the module "on the fly" through the learning and simulation environments. The solution to the problem required hand calculations utilizing the theory provided in the module. Finally, the module was adopted by each student to design the proper corridor given projected Sooner City traffic volumes. A post-project survey was conducted to evaluate the module's effectiveness.

The questions and a compilation of the responses obtained from thirty-six students are presented in Table 7.1. The means, standard deviations, and other test statistics describing student responses are illustrated in Table 7.2. The level of significance about the mean's difference from the value of 3.0 was tested based on the t-distribution since the value of 3.0 represents neither 'true' nor 'false'. The assumption is that the data has a normal distribution and that its variance is unknown [100]. The equation to compute the test statistic (t_0) in the table 7.2 is

$$t_0 = \frac{\overline{x} - u_0}{s/\sqrt{n}} \tag{7.1}$$

Table 7.1 Survey Questions and Results about the Traffic Engineering Module

Statements	Definitely false	More false than true	Neither	More true than false	Definitely true
1. The module helped me understand the principles behind the transportation corridor design	0	4	6	18	8
2. The module helped me to better visualize the transportation corridor design	0	0	1	11	24
3. The module helped me complete the design project faster	1	1	4	9	21
4. The module allowed me to complete the corridor design without understanding the principles.	13	10	4	5	4

The total number of students that responded was 36.

Table 7.2 Test Statistics about the Survey on the Traffic Engineering Module

Statements	Mean	Standard Deviation	Test Statistic (t_0)
1	2.1667*	0.91026	-5.4927
2	1.3611	0.54263	-18.131
3	1.6667	0.98561	-8.1166
4	3.6389	1.3970	2.7440

* The mean based on the following scale:

1 = definitely true, 2 = more true than false, 3 = neither, 4 = more false than true, 5 = definitely false.

Though the responses are subjective and do not provide a truly quantitative indication of the students' improvement in knowledge, they do provide useful insight. One of the objectives of the module was to help students visualize the problem. Student responses to question two suggest, at the 0.0005 level of significance, the module was successful in this regard. The second main objective of the module was to help students better understand the underlying traffic principles. Student responses to question one indicate, at the 0.0005 level of significance, this goal was accomplished, although not as resoundingly as for visualization (see the mean associated with question one). The third objective was to provide a useful tool for learning basic concepts of traffic engineering. Student responses to questions three reveal, at the 0.0005 level of significance, that the module was effective. For question four, it is reasonable to have a mean greater than 3.0. This is because the module was not designed to allow the students to complete the corridor design without understanding the principles.

7.1.2 Assessment on the Structural Analysis Module

The second assessment was conducted to determine the effectiveness of the structural analysis module at the University of Oklahoma in the fall of 2000. The professor first demonstrated in class how the module could be used to solve frame problems, and two homework problems were then assigned. The students were offered five bonus points for using the structural analysis module to check their homework solutions.

The survey questions and their corresponding results are shown in the Table 7.3. Twelve students in all responded to the survey. Table 7.4 summarizes the means, standard deviations, and other test statistics performed on the student responses to the questions about the module. The level of significance about the mean's difference from the value of 3.0 was tested based on the t-distributions since the value of 3.0 represents neither good nor bad. The assumption is that the data has a normal distribution and that its variance is unknown [100].

Table 7.3 Survey Questions and Results about Structural Analysis Module

Questions	Useless	Not so good	No opinion	Good	Excellent
1. How good is this module at helping you understand the concepts of frame or truss structures?	0*	1	1	7	3
2. How good is this module at helping you better visualize the computational results of frames or trusses such as the moment diagram and deflection?	0	0	0	7	5
3. How good is the module at helping you check homework solutions?	1	2	1	5	3
4. How good is the module at encouraging you to design new truss or frame structures?	0	0	5	5	2
5. How good is the Virtual City at helping you visualize 3D models?	0	0	6	5	1

* Number of students who responded "Useless". The total number of students that responded was 12.

Table 7.4 Test Statistic about the Survey on the Structural Analysis Module

Questions	Mean	Standard Deviation	Test Statistic (t_0)
1	2.0	0.85280	-4.0620
2	1.5833	0.51493	-9.5306
3	2.4167	1.3114	-1.5408
4	2.2500	0.75378	-3.4467
5	2.4167	0.66856	-3.0223

* The mean based on the following scale:

1 = excellent, 2 = good, 3 = no opinion, 4 = not so good, 5 = useless.

From the responses to questions one and two, it is concluded, at the 0.001 level of significance, that the module was successful in helping students better visualize the computational results and understand the concepts of truss and frame structures. The responses to question three indicate, at the 0.1 level of significance, that the students believed that the module was useful in checking homework solutions. The responses to questions four and five suggest, at the 0.01 level of significance, that the module encouraged students to design new structures outside of the assigned homework and helped visualize 3D models. However, it is interesting to note that half of the respondents had no opinion in response to question five. This probably means that they did not try to design a bridge and deposit it into the 3D virtual world.

In addition to answering survey questions, these twelve students also provided useful comments about the structural analysis module. Examples of positive comments are, "If I would have learned to use this (module) earlier in this semester I think it would have helped me tremendously" and "The graphics and bending demonstrations and shear and moment diagram are great." Major complaints were that user interface was not user-friendly and that it was easy to forget to maintain consistency among all units.

7.2 Assessment on the Collaborative Geometric Modeling and Engineering Analysis Modules

Like industry, academic institutions need tools to help students collaborate on design objects. To better understand the usefulness of the collaborative modules, an assessment was conducted at the University of Oklahoma in the spring of 2001. Both the collaborative geometric modeling and engineering analysis modules were used since they are similar in concept. The design class, Introduction to Computer Aided Design (CAD), with seventeen senior and graduate students was selected since the students were also introduced to general-purpose and non-Internet-based CAD programs.

The survey was conducted in a number of steps. First, a class presentation was given discussing the purposes of the modules and showing the steps of how to use them.

Second, an assignment and a survey form were distributed to the students along with help documents (Appendix I and J). The students were required to form multiple teams. Team members were required to work jointly on the assignment. Each team needed to submit only one copy of the solution. The assignment was graded satisfactory or unsatisfactory. Team members were required to submit the surveying form individually. The survey questions and their answers are presented in Table 7.5.

Table 7.5 Surveying Questions and Results on the Collaborative Modules

Questions	Strongly disagree	Disagree	No opinion	Agree	Strongly agree
1. It is helpful if geographically distributed engineers can work in a well-designed collaborative design environment.	0	0	1	9	7
2. The Internet should be used for collaborating engineering design and analysis.	0	1	1	9	6
3. A collaborative design environment encourages spirit of teamwork when it is used to complete homework jointly.	0	1	3	8	5
4. A collaborative design environment encourages collaborative learning of remote users.	0	2	3	9	3
5. The engineering analysis module is good at helping you better visualize stresses and displacements.	0	2	0	9	6
6. The Virtual City is good at presenting the big picture and 3D visualization.	0	1	5	6	5
7. Internet-based engineering education with capabilities of 3D engineering design and analysis will be popular in five years.	0	2	6	5	4
8. It helped to collaborate online using the design environment for the homework.	0	4	6	5	2
9. It was easy to use the distributed collaborative design environment.	1	9	2	5	0
10. It was helpful to see a 3D stress state while designing the beam.	0	1	4	10	2

The total number of students that responded was 17.

The assignment was an optimization problem that required the students to design a rectangular beam with minimum weight subject to von Mises stress. To finish the assignment, the students needed to use the geometric modeling module to design a beam and then use the analysis module to perform the stress analysis. As it was an optimization problem, the students needed to repeat the design-analysis several times to obtain a reasonable solution. The students were required to work collaboratively on the assignment over the Internet.

Table 7.6 Test Statistics about the Survey on the Collaborative Modules

Questions	Mean	Standard Deviation	Test Statistic (t_0)
1	1.6471*	0.60634	-9.1997
2	1.8235	0.80896	-5.9964
3	2.0000	0.86603	-4.7609
4	2.1765	0.95101	-3.7503
5	1.8824	0.92752	-4.9681
6	2.1176	0.92752	-3.9225
7	2.3529	0.99632	-2.6779
8	2.7059	0.98518	-1.2308
9	3.3529	0.99632	1.4604
10	2.2353	0.75243	-4.1903

* The mean based on the following scale:

1 = strongly agree, 2 = agree, 3 = no opinion, 4 = disagree, 5 = strongly disagree.

Table 7.6 summarizes the means, standard deviation, and other test statistics for the nine questions [100]. The level of significance about the mean's difference from the value of 3.0 was tested based on the t-distribution since the value of 3.0 represents neither 'agree' nor 'disagree'. The assumption is that the data has a normal distribution and that its variance is unknown [100]. The results demonstrate particularly useful information about the two collaborative modules.

One of the objectives for this survey was to evaluate whether the idea of collaboration on the Internet is useful for design and analysis. The responses to questions one, two, three, and four suggest, at the 0.001 level of significance, that the idea is useful in this regard. Another objective of the survey was to evaluate whether 3D visualization is useful. The responses to questions five, six, and ten indicate, at the 0.001 level of significance, that the students enjoyed seeing 3D models. The responses to question eight reveal that the modules help the students complete their homework with the 0.125 level of significance. This implies that the environments were only mildly helpful. The responses to question nine were a surprise. The results demonstrate, with the 0.1 level of significance, that the students did not think the interface design of these two environments was easy to use. This suggests that it is always a challenge to design a user-friendly interface. There are two reasons for this negative response. The first is that the most students have not taken the finite element method course and they had difficulty in understanding the concepts of the finite element analysis. The second reason is that the students are comparing the collaborative environments with large commercial programs, such as Pro/Engineer and SolidWorks. The responses to question seven show, at the 0.1 level of significance, that the students believed Internet-based engineering education with 3D visualization is the direction of the future.

Some students also gave useful comments about the collaborative modules. The students expected an interface that can manage concurrent procedures effectively. They expected an "undo" operation and direct voice communication instead of a chat room. One of the major complaints was that when two participants initiate actions simultaneously, their actions could conflict and make it difficult to work efficiently.

Chapter 8: Conclusion

8.1 Summary

The main focus of this research was to provide an infrastructure for engineering education, test the concept of distributed collaborative design and analysis, develop and implement the Virtual City environment, and assess the environment's effectiveness in the real world. A three-tier architecture was adopted in the development of the environment, which contains an online database server, a Web server as well as multi-user servers, and client browsers. The environment is composed of five components: a 3D virtual world, multiple Internet-based multimedia modules, an online database, a collaborative geometric modeling module, and a collaborative engineering analysis module. The environment is open to the public at www.vcity.ou.edu, and was designed using multiple Internet-based technologies, such as Shockwave, Java, Java 3D, VRML, Perl, ASP, SQL, and the database. These various technologies together formed the basis of the environment and were programmed to communicate smoothly with each other.

The online database was designed to manage the changeable data related to the environment, because it is an efficient approach to save, delete, retrieve, and search data. The virtual world was used to implement 3D visualization and tie the multimedia modules together. Students are allowed to build segments of the 3D virtual world upon completion of appropriate undergraduate courses in civil engineering. The end result is a complete virtual world that contains designs from all of their coursework and is viewable on the Internet. The environment is an educational system with rich content, which can be used to teach multiple engineering topics with the help of 3D visualization, animations, and simulations. Each multimedia module can be used to teach one specific engineering topic.

The concept of collaborative design and analysis using the Internet was investigated and implemented. The key elements of collaboration such as sharing information, communication, and manipulation of design objects were integrated in the collaborative modules. Geographically dispersed users can build the same geometric model simultaneously over the Internet and communicate with each other through a chat room. Likewise, they can conduct finite element analysis collaboratively on the same object through the Internet. They can mesh the same object, apply the same boundary conditions and forces, obtain the same analysis results, and discuss the results through the Internet.

Three assessments were conducted over a period of three semesters to evaluate the effectiveness of the environment. Four modules were evaluated in the assessment: traffic engineering, structural analysis, collaborative geometric modeling, and collaborative engineering analysis modules. The results were analyzed statistically, which demonstrates that the Virtual City is helpful in engineering education and design.

There exist also a few limitations in this research. Feature-based and dimension-driven strategies are not implemented in the collaborative geometric modeling module while these are standard features in modern CAD packages. The collaborative engineering analysis module cannot be used to auto-mesh arbitrary geometric shapes. The client/server strategy utilized in the engineering analysis module cannot be employed to solve large complex FEA problems due to the limited computing power of the client machines. Voice communication is not implemented in the collaborative environments. More assessments are necessary to evaluate the effectiveness of the multimedia modules.

8.2 Discussion of the Contributions

This research has led to the development of an Internet-based Virtual City for engineering education and design. It is the first Internet-based prototype integrating 2D simulations and 3D visualization in one environment. In addition, it is the first collaborative framework for engineering education. It is also the first Internet-based application that can be used to conduct 3D finite element analysis collaboratively with original considerations of implementation. Numerous Internet technologies were employed and programmed to talk with each other smoothly. Three assessments were conducted and analyzed of the effectiveness of the Virtual City.

The four essential elements: interactivity, collaborative learning, 3D visualization, and encouragement of creativity and teamwork, for Internet-based engineering education were emphasized in the development of the Virtual City. Interactivity is achieved by developing multiple multimedia modules that cover numerous engineering topics. The user can modify multiple parameters, and draw a truss structure, frame structure, or cross section as input information. The results of the simulations are then presented using animation, graphics, contours, and tables. An Internet-based 3D virtual world is utilized for 3D visualization to offer a central location managing various 3D structures created by different multimedia modules. Structures in the 3D virtual world, such as buildings, steel structures, bridges, highways, and dams, are generated from different multimedia modules. The 3D virtual world therefore ties all of simulations together in one environment. Collaborative learning and teamwork are encouraged when the user uses the collaborative geometric modeling and engineering analysis modules. Generic modules, such as the structural analysis and piping network modules, with minimizing the restriction on the user's input were designed to encourage creativity.

In total, nine multimedia modules with unique features were developed:

1. The traffic engineering module uses various colors to demonstrate different levels of service. The cars on the highway are moving with significantly different speeds at different levels of service, which gives a direct impression of the problem to the students.
2. Using the steel structure module, a complex steel structure can be designed dynamically in the 3D virtual world through the modification of three parameters. The user can then view the details of how numerous bays connect with each other.
3. The surveying module is a paradigm that demonstrates the power of using various Internet technologies to explain complex engineering concepts. The unique creativity of the module is that it can simultaneously display 2D contours and 3D surfaces over the Internet.
4. The foundation simulation was found to be the first Shockwave simulation to implement finite element analysis visually over the Internet. The interface is user-friendly because the user does not need to prepare the data using other programs. The user can perform automatic meshing by moving a slider bar. This tremendously reduces the tedious work of data preparation such as the numbering of nodes.

5. The soil module is a straightforward and intuitive illustration to demonstrate the superposition method. The user can add, delete, or move the forces to experience the different combined effects using the contour lines.
6. The consolidation module is an excellent time-based example, which allows the user to speed up and slow down the consolidation process by changing the value of the time parameter and then see the details of the process.
7. As for the structural analysis module, no similar Internet-based frame solver was found during module development. The user can define the truss and frame structures by drawing individual members, which is an intuitive and convenient approach. The computational results are visually demonstrated. The structure as well as the forces and boundary conditions can be saved on the server and retrieved later using the simulation. The module can help students design simple truss and frame structures with analytical results.
8. The concrete module illustrates a successful example of using the geometric object as input by allowing the user to draw the desired geometric objects. It can recognize the different shapes of the geometric objects and choose appropriate formulas based on the shapes.
9. Similar to the structural analysis and concrete modules, the piping network module provides an intuitive way to draw, move, and delete the pipes. The user can visually define the reservoir and demands. The simulation automatically records the index of each node and pipe, which minimizes the tedious work of preparing the network's configuration. The computational results are graphically presented, and the user therefore does not need to read the result tables.

The importance of essential elements about distributed collaboration was discussed. The key elements to distributed collaboration, such as sharing information, communication, and manipulation of design objects, were implemented in the collaborative modules. The geometric modeling module is the first collaborative geometric building tool for engineering education when in the investigation stage. Its collaborative capability encourages team spirit. It was integrated seamlessly with the 3D virtual world by depositing the generated 3D geometric objects into the virtual world. The generated geometric objects can be retrieved and analyzed by the collaborative engineering analysis module. Furthermore, its architecture is different from that of conventional collaborative geometric modeling applications. Conventional applications usually have a geometric modeling engine on the server, and a client-side application is mainly used to display the model. The traffic between the server and client is usually high in such applications. However, in this research, the multi-user server only manages communication between team members, and the client-side application takes care of modeling. Due to the adoption of this architecture, the user can interact directly with the geometric model to accomplish a variety of operations such as selecting geometric entities. This architecture also minimizes network traffic, because there is no need to download the geometric model after each operation.

The collaborative engineering analysis module is the first prototype of the Internet-based distributed collaborative environment for 3D finite element analysis that allows users to work collaboratively on the same analysis object simultaneously. It reads the geometric data from the collaborative geometric modeling and then seamlessly links both modules together. The user can interact directly with the geometric model to perform operations, such as applying, editing, and deleting boundary conditions and forces. The team members share operation commands instead of results so that the network traffic associated with collaboration is minimized. The database is utilized to manage the geometric files used in the engineering analysis, which is particularly efficient. The token is employed to avoid sending multiple copies of information to the new user. The globally unique ID is assigned to the generated object in the creator's computer and then propagated to the object generated by remote user's computers. The unique IDs are used to distinguish objects in a distributed environment. Object serialization is utilized to transmit data over the Internet conveniently and efficiently.

Numerous Internet technologies were employed, such as HTML, JavaScript, Shockwave, VRML, Java, Java 3D, ASP, SQL, Perl, and the SQL online database. They were utilized together and programmed so that they communicate smoothly with each other. The customized 3D virtual worlds are generated using ASP, VRML, and the online database. Shockwave and Perl talk to each other to create new virtual objects. Shockwave and Java communicate seamlessly to allow the user to design geometric models collaboratively. In addition to these technologies, numerous multimedia applications, such as Flash, Premiere, Photoshop, Freehand, and Dreamweaver, were used also to develop the Virtual City.

A few unique Lingo programming techniques were employed in the development of the environment. The object-oriented concepts were used extensively to integrate the vector-based graphic techniques. This significantly increases the readability of the codes. Standard stack data structures were simulated by the list data structures of Lingo to solve the management problem of the channels efficiently in Shockwave.

Three assessments were conducted over a period of three semesters to evaluate the effectiveness of the Virtual City because of its use for engineering education. The results were analyzed statistically, and the analysis shows that the Virtual City is helpful in engineering education, design, and analysis.

8.3 Recommendations for the Future Work

The Virtual City environment is still at its infancy, however its concepts can provide the basis of a virtual university for engineering education. Its concepts can be extended to develop such an environment that allows the students to design virtual parts, assemble virtual products, and simulate their manufacturing processes in a virtual factory. In this environment, the user can learn engineering principles by building the products and testing their manufacturability virtually.

Currently, the multimedia modules in the Virtual City are mainly for civil engineering, and future research may extend to mechanical engineering, electrical engineering, and chemical engineering. Additional carefully designed evaluation strategies are needed to assess the effectiveness of the multimedia modules, 3D virtual world, and entire environment. Control groups may be used in the assessment.

Agent-based technologies may be used to design multimedia modules in the future. With agent-based technologies, the modules are not individually separate entities, but entities that can communicate with each other. For example, when the students design a highway system with specific traffic flows using the traffic module, the traffic data may affect the design of the bridge when using the structural module. Employing agent-based technologies, multiple multimedia modules can form an educational system with smooth communication. The system can then let the students experience the procedure of real-world designs.

In the Virtual City environment, VRML, Java 3D, and Shockwave were used to implement 3D visualization. With the recent introduction of Director 8.5, it is possible to use only Shockwave to implement an Internet-based 3D environment. The automatic downloading feature of Shockwave can minimize the user's trouble of finding appropriate plug-ins.

New features may be added to the distributed collaborative design and analysis, such as feature-based CAD, dimension-driven strategies, meshing of arbitrary geometric models, privilege management, and voice communication. The feature-based CAD is a standard feature in modern commercial CAD packages. These commercial packages also support dimension-driven strategies when the geometric models are built. Advanced preprocessing CAE tools allow the user to auto-mesh geometric models with arbitrary shapes. Privilege management is important, because it can impose multiple security levels on the system and resolve the action conflicts of distributed users. It is natural to design voice communication in a collaborative environment, because it offers convenience by allowing users to exchange ideas quickly.

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Appendices

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Appendix A: HTML Code With JavaScript

```
<html>
<head>
<title>Home of virtual city</title>
<meta http-equiv="Content-Type" content="text/html; charset=iso-8859-1">

<script language="JavaScript">
//--------------------------function to get cookie value--------------------------
function getCookieVal (offset) {
  var endstr = document.cookie.indexOf (";", offset);
  if (endstr == -1)
    endstr = document.cookie.length;
  return unescape(document.cookie.substring(offset, endstr));
}
//--------------------------end function to get cookie value----------------------

//--------------------------function to get the cookie----------------------------
function GetCookie (name) {
  var arg = name + "=";
  var alen = arg.length;
  var clen = document.cookie.length;
  var i = 0;
  while (i < clen) {
    var j = i + alen;
    if (document.cookie.substring(i,j) == arg)
      return getCookieVal(j);
    i = document.cookie.indexOf(" ", i) + 1;
    if (i == 0) break;
  }
  return null;
}

//--------------------------end function to get the cookie------------------------
var data = GetCookie("dir");
if (data == null) {
  top.location = "error/login_error.htm"
}
</script>
</head>

<frameset cols="118,552*" frameborder="NO" border="0" framespacing="0" rows="*">
  <frame name="menu" scrolling="NO" src="homeMenu.htm" marginwidth="0"
marginheight="0" frameborder="NO">
  <frame name="mainFrame" src="introduction.htm">
```

```
</frameset>
<noframes><body bgcolor="#FFFFFF">
</body></noframes>
</html>
```

Appendix B: Lingo Script with the Stack Data Structure

```
-- creating an edge for 3D model
-----------------------------------
global edgeIndexStack,spriteIndexStack,maxEdgeNum,edgeNum
global edgeList
-----------------------------------
property myVPos, vPList, pList, mySprite
property myBlend, myInk, myMember
property initMember
property myEdgeIndex,myColor, myWidth,newEdge
property firstPoint, secondPoint

on new me
 theInk = 36
 theBlend =100
 theColor = rgb(0,255,0)
 --pop up a value from spriteIndexStack
 spriteNumber = spriteIndexStack[1]
 deleteAt spriteIndexStack,1

 myColor = theColor
 mySprite = spriteNumber
 myInk = theInk
 myBlend = theBlend

 initMember = sprite(mySprite).member

 sprite(spriteNumber).puppet = true
 sprite(spriteNumber).ink = theInk
 sprite(spriteNumber).blend = theBlend

 ---------- here we need to create a new edge vectorShape

 newEdge = new(#vectorShape)
 edgeNum  = edgeNum + 1
 -- edgeIndexStack is to keep track of the index of edges
 newEdge.name = "edge"&string(edgeIndexStack[1])
 myEdgeIndex = edgeIndexStack[1]
 deleteAt edgeIndexStack,1
 edgeName = newEdge.name
 newEdge.closed = false
 newEdge.strokeColor = myColor
 newEdge.strokeWidth = 1
 newEdge.antialias = true
```

```
  newEdge.regPoint = point(0,0)  -- set reg point at left top
  ---------------------------------------------------

  sprite(mySprite).member = member(edgeName)
  myMember = edgeName
  sprite(mySprite).visible = true
  --Here firstPoint is used as a flag
  firstPoint = -1
  return me
end

on kill me
  sprite(mySprite).member = initMember
  ---------------new features--------------
  erase member myMember
  --push the values back into the stack
  add edgeIndexStack,1,myEdgeIndex
  edgeNum = edgeNum - 1
  add spriteIndexStack,1,mySprite
  --edgeIndexStack.sort()
  spriteIndexStack.sort()
end

on drawMe me,firstLastPoint
  --update the edge
  member(myMember).vertexList=[[#vertex:firstLastPoint[1]],[#vertex:firstLastPoint[2]]]
  firstPoint = firstLastPoint[1]
  secondPoint = firstLastPoint[2]
  --updateStage
end

on moveNodeMe me,locatedPoint,newPointPos
  sprite(mySprite).visible = true
  --here we need to know locatedPoint's order
  if locatedPoint.locH = firstPoint.locH and locatedPoint.locV = firstPoint.locV then
    member(myMember).vertexList=[]
    member(myMember).vertexList=[[#vertex:newPointPos],[#vertex:secondPoint]]
    --firstPoint = newPointPos
  end if

  if locatedPoint.locH = secondPoint.locH and locatedPoint.locV = secondPoint.locV then
    member(myMember).vertexList=[]
    member(myMember).vertexList=[[#vertex:firstPoint],[#vertex:newPointPos]]
    --secondPoint = newPointPos
  end if
  updateStage
```

```
end

on updateFirstSecondPoint me
  first = getProp(member(myMember).vertexList[1],#vertex)
  second = getProp(member(myMember).vertexList[2],#vertex)
  firstPoint = first
  secondPoint = second
end

on setEdgeColor me,theColor
  newEdge.strokeColor = theColor
  updateStage
end

on restoreEdgeColor me
  newEdge.strokeColor = myColor
  updateStage
end

on setEdgeWidth me, theWidth
  newEdge.strokeWidth = theWidth
end

on setInk me, theInk
  sprite(mySprite).ink = theInk
  myInk = theInk
end

on setBlend me, theBlend
  sprite(mysprite).ink = 32
  myInk = 32
  sprite(mysprite).blend = theBlend
  myBlend = theBlend
end
```

Appendix C: ASP Script for the Dynamic VRML

```
<%@ LANGUAGE="VBSCRIPT"%>
<%
Option Explicit
Dim fso, MyFile,RootDir,line,viewOrder
Dim vpName(12),px(12),py(12),pz(12),ox(12),oy(12),oz(12),rotAngle(12),volume(12)
Dim firstViewPoint,i
Dim userID, teamID
Dim Connect, onAccount,SQL


response.Expires = 0
response.Buffer = TRUE
response.Clear

response.ContentType = "x-world/x-vrml"

RootDir = server.MapPath("/vcity") &"\users\ground\"
'RootDir ="F:\www\soonercity\users\ground\"

Set fso = CreateObject("Scripting.FileSystemObject")

'*********************
'Read in the first part of the ground.wrl
'*********************

Set MyFile = fso.OpenTextFile(RootDir&"groundfirst.wrl", 1,0)
Do
        line = myFile.ReadLine
        line = line+vbcr
   response.Write(line)
Loop until MyFile.AtEndOfStream
MyFile.close

userID=Request.Cookies("dir")
if userID ="" then
  userID = "guestGroup"
End if

teamID = userID

userID = userID&"/"

loadModel  "ground/landscape.wrl", 0,0,0
```

```
loadModel userID&"building.wrl", -600, 0, -100

'loadModel  userID&"road.wrl", 500, 0, 0

loadModel  userID&"steel.wrl",-600, 0, 100

'loadModel userID&"tower.wrl",-800, 0, 100

loadModel userID&"hwy.wrl",-700, 0, 0
loadModel userID&"dam.wrl",0, 0, 0
loadModel userID&"bridge.wrl",340, 0, 0
loadModel userID&"consolLand.wrl",0, 0, 0
loadModel userID&"concrete.wrl",0, 0, 0

loadModel userID&"piping.wrl",0, 0, 0


''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
'Here I retrieve the files in the database for virtual world
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
Set Connect = Server.CreateObject("ADODB.Connection")
Connect.Open "DSN=vcity","sa",""
SQL = "select fileName from teamFolderVRMLFiles where teamID = '"&teamID&"';"
Set onAccount = Connect.execute(SQL)

'Loop to report the fileNames
if onAccount.EOF = true then
 'do nothing
Else
  Do Until onAccount.EOF
          loadModel userID&onAccount("fileName"),0, 0, 0
          onAccount.MoveNext
  Loop
End if
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
'****************************
'Read in the last part of the ground.wrl
'****************************

Set MyFile = fso.OpenTextFile(RootDir&"groundlast.wrl", 1,0)
Do
          line = myFile.ReadLine
          line = line+vbcr
   response.Write(line)
Loop until MyFile.AtEndOfStream
MyFile.close
```

```
'******************
'load view point
'******************
vpName(1) = "Start"
px(1) = 2100.82
py(1) = 814.129
pz(1) =  1361.31
ox(1) = -0.193413
oy(1) = 0.974006
oz(1) =  0.117914
rotAngle(1) = 1.11853
volume(1) = 0.47854
'***************
vpName(2) = "Bird"
px(2) =2568.38
py(2) = 1360.35
pz(2) = -211.856
ox(2) = -0.226229
oy(2) = 0.937523
oz(2) = 0.26433
rotAngle(2) = 1.63841
volume(2) = 0.47854
'***************
vpName(3) = "River"
px(3) =1624.2
py(3) = 579.964
pz(3) = 1026.41
ox(3) =-0.300093
oy(3) = 0.932157
oz(3) =0.202554
rotAngle(3) = 1.25345
volume(3) = 0.47854
'***************
vpName(4) = "Steel"
px(4) =488.203
py(4) = 607.908
pz(4) =871.398
ox(4) =-0.428447
oy(4) =0.901829
oz(4) = 0.0560088
rotAngle(4) =  0.912546
volume(4) = 0.47854

'***************
```

```
vpName(5) = "Tower"
px(5) =301.577
py(5) =  523.342
pz(5) = 463.405
ox(5) =          -0.287543
oy(5) =0.945671
oz(5) =  0.151741
rotAngle(5) = 1.32004
volume(5) = 0.47854

'****************
vpName(6) = "Building"
px(6) = 14.0581
py(6) =  364.239
pz(6) =  441.587
ox(6) =          -0.42273
oy(6) =  0.888205
oz(6) =  0.179974
rotAngle(6) = 1.20197
volume(6) = 0.47854

vpName(7) = "Lake"
px(7) =1577.16
py(7) =  745.407
pz(7) =  356.233
ox(7) =          -0.41338
oy(7) =  0.882569
oz(7) =  0.22403
rotAngle(7) = 1.10696
volume(7) = 0.47854

vpName(8) = "Bridge"
px(8) =705.351
py(8) =  120.952
pz(8) =  176.219
ox(8) =          -0.351491
oy(8) =   0.921591
oz(8) =  0.164697
rotAngle(8) = 0.929157
volume(8) = 0.47854

vpName(9) = "Concrete"
px(9) =-532.531
py(9) = 53.4159
pz(9) =  47.2986
ox(9) =          -0.195245
```

```
oy(9) =  0.970839
oz(9) =  0.139109
rotAngle(9) =  1.26621
volume(9) = 0.47854

vpName(10) = "Piping"
px(10) = 2401.2
py(10) =  -1239.86
pz(10) =  912.444
ox(10) =        0.26581
oy(10) =   0.943529
oz(10) =  -0.197735
rotAngle(10) =  1.33527
volume(10) =0.47854



'****************

'****************
'Load view point
'***************

firstViewpoint = request.cookies("currentViewPoint")
if firstViewpoint ="" then
 firstViewpoint = 2
end if

loadViewPoint
vpName(firstViewpoint),px(firstViewpoint),py(firstViewpoint),pz(firstViewpoint),_
ox(firstViewpoint),oy(firstViewpoint),oz(firstViewpoint),rotAngle(firstViewpoint),volu
me(firstViewpoint)
For i = 1 To 10
  If i <> firstViewpoint Then
        loadViewPoint vpName(i),px(i),py(i),pz(i),ox(i),oy(i),oz(i),rotAngle(i),volume(i)
       End If
Next
'*******************


response.end

%>

<%
```

```
'**********************
'Use this function, we could save a lot of effort to write codes
'**********************
Function loadModel(path,x,y,z)
response.write("DEF building Transform {"& vbcr)
response.write("children        Inline {" & vbcr)
response.write("url "& chr(34) & path & chr(34) &vbcr)
response.write(" }"+vbcr)
response.write("  translation "& x &" "& y &" "&  z &vbcr)
response.write("}"&vbcr&vbcr)
End Function

'**************************
'loadViewPoint
'**************************
Function loadViewPoint(vpName,px,py,pz,ox,oy,oz,rotAngle,viewVolume)
response.write("DEF "& vpName &" Viewpoint {" & vbcr)
response.write("position        "& px & "  "& py & " " & pz & vbcr)
response.write("orientation    "& ox & " "& oy & " " & oz & " "& rotAngle & vbcr)
response.write("fieldOfView  " & viewVolume &vbcr)
response.write("jump FALSE" & vbcr)
response.write("description "& chr(34) &  vpName  & chr(34) &vbcr)
response.write("}"&vbcr &vbcr)
End Function
%>
```

Appendix D: Java Multi-user Server

```
package edu.ou.eml.fea3d.server;

import com.sun.media.jsdt.*;

public class Fea3DServer implements Fea3DDebugFlags {

  private static String fea3DSessionName = "Fea3DSession";
  private static String design3DSessionName = "Design3DSession";

  private static Channel createGroupChan;

  public static void main(String args[]) {
    Fea3DClient client     = null;
    Session   fea3DSession = null;
    Session design3DSession = null;

    URLString  urlFea3D       = null;
    String    implementationType = null;
    String    serveName    = null;
    int       serverPort    = 0;

    if (Fea3DServer_Debug) {
      System.err.println("Design3D and Fea3D Server: main.");
    }

    serveName    = getHost(args);
    serverPort    = getPort(args);
    implementationType = getType(args);
    urlFea3D    = URLString.createSessionURL(serveName, serverPort,
    implementationType, fea3DSessionName);

    URLString urlDesign3D = URLString.createSessionURL(serveName, serverPort,
    implementationType, design3DSessionName);

    try {
      if (RegistryFactory.registryExists(implementationType) == false) {
        RegistryFactory.startRegistry(implementationType);
      }
      client   = new Fea3DClient("Server");
      //For Fea3D
      fea3DSession = SessionFactory.createSession(client, urlFea3D, true);

      //For Design3D
```

```
            design3DSession = SessionFactory.createSession(client, urlDesign3D, true);

            System.err.println("Setup and bound Design3D and Fea3D server.");

        } catch (JSDTException e) {
            System.err.println("Design3D and Fea3D Server: main: shared data exception: " +
e);
            if (Fea3DServer_Debug) {
                e.printStackTrace();
            }
        }
    }


    private static String
    getHost(String args[]) {
        String defHost = "vcity.ou.edu";  /* Default host name for connections. */
        int length = args.length;

        if (Fea3DServer_Debug) {
            System.err.println("Design3D and Fea3D Server: getHost.");
        }

        for (int i = 0; i < length; i++) {
            if (args[i].equals("-server")) {
                if (++i < length) {
                    return(args[i]);
                }
            }
        }
        return(defHost);
    }


    private static int
    getPort(String args[]) {
        int defPort = 4461;  /* Default port number for connections. */
        int length = args.length;

        if (Fea3DServer_Debug) {
            System.err.println("Design3D and Fea3D Server: getPort.");
        }

        for (int i = 0; i < length; i++) {
            if (args[i].equals("-port")) {
                if (++i < length) {
```

```
                return(Integer.parseInt(args[i]));
            }
        }
    }
    return(defPort);
}


private static String
getType(String args[]) {
    String defType = "socket";   /* Default Session type. */
    int length = args.length;

    if (Fea3DServer_Debug) {
        System.err.println("Design3D and Fea3D Server: getType.");
    }

    for (int i = 0; i < length; i++) {
        if (args[i].equals("-type")) {
            if (++i < length) {
                return(args[i]);
            }
        }
    }
    return(defType);
}
}
```

Appendix E: Java Multi-user Client

```
package edu.ou.eml.fea3d.collaboration;
import edu.ou.eml.fea3d.*;
import edu.ou.eml.fea3d.data.*;


//standard import
import com.sun.media.jsdt.*;
import com.sun.media.jsdt.event.*;
import java.awt.*;
import java.awt.event.*;
import java.applet.Applet;
import javax.vecmath.*;
import java.io.*;
import javax.media.j3d.*;

//*******************************
//The general idea is simple. I group the communications.
//A set of coomunications share a generalChannel. In this case, we can
//seperate the sending and receiving prcessing.
//*******************************

public final class Fea3DUser implements Fea3DDebugFlags
{
   public static final int MESH_CREATE = 10;
   public static final int MESH_REMOVE =  11;

   public static final int GENERAL = 0;
   public static final int MESH = 1;
   public static final int CHATROOM = 2;
   public static final int COMPUTE = 3;
   public static final int BC = 4;
   public static final int POINT_FORCE = 5;
   public static final int VISUALIZATION = 6;
   public static final int FILE_UNIT = 7 ;
   public static final int ZOOM = 8 ;
   public static final int DISTRIBUTED_FORCE = 9 ;

   /** The clientName of this Client. */
   public String clientName;

   /** The  session that this client application will join. */
   private Session session;
```

```
/** The client that will be joining the session and generalChannel. */
public static Fea3DClient client;

/** The generalChannel that this client application will use to send data. */
private Channel generalChannel, meshChannel, chatChannel, computeChannel;
private Channel bcChannel , pointForceChannel, visualizationChannel;
private Channel fileUnitChannel, zoomChannel;
private Channel distributedChannel;

/** The data that will be sent over the generalChannel. */
private Data data;

/** Indicates if the client is successfully connected to the server. */
public boolean connected = false;

//Mouse token is used to ensure only one user can rotate the object
//at some particular time
public static Token mouseToken;
private String mouseTokenName = null;

public static Token newUserToken;
private String newUserTokenName = null;

//Team name is a base that is used to separate communication between teams
private String teamName = null ;
private String meshChannelName = null ;
private String chatChannelName = null ;
private String computeChannelName = null ;
private String bcChannelName = null ;
private String pointForceChannelName =  null ;
private String visualizationChannelName =  null ;
private String  fileUnitChannelName =  null ;
private String  zoomChannelName =  null ;
private String distributedChannelName = null;

/* Default setup, will mostly be overriden by attributes. */
String  serverName    = DataContainer.serverName ;

int     serverPort    = 4461;
String  sessionImplementationType = "socket";

private ChannelConsumer generalChannelConsumer,
meshChannelConsumer, chatChannelConsumer, computeChannelConsumer,
bcChannelConsumer, pointForceChannelConsumer, visualizationChannelConsumer,
fileUnitChannelConsumer, zoomChannelConsumer, distributedChannelConsumer ;
```

```
public Fea3DUser()
{
   //Please notice that client should be passed from HTML pages
   clientName = DataContainer.userName ;
   teamName = DataContainer.newChannelName;

   meshChannelName = teamName + "mesh" ;
   chatChannelName = teamName +"chat" ;
   computeChannelName = teamName +"compute" ;
   bcChannelName = teamName +"bc" ;
   pointForceChannelName = teamName+"pointForce" ;
   visualizationChannelName = teamName+"visualizatoin";
   fileUnitChannelName = teamName + "fileUnit" ;
   zoomChannelName =  teamName + "zoom" ;
   distributedChannelName =  teamName + "distributed" ;

   mouseTokenName = "mouseToken" ;
   newUserTokenName = "newUser" ;

}

final public void connect()
{
   if (teamName == null)
   {
      System.out.println("Connection failed since no team Name is provided");
      return;
   }
   if (connected) {
      return;
   }

   String   sessionName   = "Fea3DSession";
   boolean  sessionExists = false;
   URLString url = null;
   if (Fea3DUser_Debug) {
      System.err.println("Fea3DUser: connect.");
   }

   try {
      try {
         url = URLString.createSessionURL(serverName, serverPort,
         sessionImplementationType, sessionName);
         // String string = "jsdt://"+serverName+":"+serverPort+"/"
         //   +sessionImplementationType+"/Session/"+sessionName;
```

```
//url = new URLString(string);
System.out.println("Fea3DUser: connect: checking: url: " + url);

int tryTime = 0;
boolean isServerAlive = true;
while (!sessionExists) {
  try {
    if (SessionFactory.sessionExists(url)) {
      System.out.println("Fea3DUser: connect:" + " found Session.");
      sessionExists = true;
    }
  } catch (NoRegistryException nre) {
    System.out.println("Fea3DUser: connect:" +
    " no registry: sleeping.");
    tryTime++;
    Thread.sleep(1000);
  } catch (ConnectionException ce) {
    System.out.println("Fea3DUser: connect:" +
    " connection exception: sleeping.");
    Thread.sleep(1000);
    tryTime++;
  }
  if (tryTime>1)
  {
    System.out.println("\nHaving trouble in connecting Fea3DServer !!!!!\n");
    isServerAlive = false;
    break;
  }
}
if (isServerAlive == true)
{
  /* Create a client. */
  System.err.println("Creating a team member...");
  client = new Fea3DClient(clientName);

  /* Join the session */
  session = SessionFactory.createSession(client, url, true);

  //general channel
  generalChannel = session.createChannel(client, teamName,true, true, true);
  //Receive and process data
  generalChannelConsumer  = new GeneralChannelConsumer() ;
  generalChannel.addConsumer(client, generalChannelConsumer );

  //Mesh channel for grouping communications about meshing
```

```
		meshChannel = session.createChannel(client, meshChannelName,true, true,
true);
		meshChannelConsumer = new MeshChannelConsumer() ;
		meshChannel.addConsumer(client, meshChannelConsumer);

		//Chat channel for discussions of users
		chatChannel = session.createChannel(client, chatChannelName,true, true,
true);
		chatChannelConsumer  = new ChatChannelConsumer() ;
		chatChannel.addConsumer(client, chatChannelConsumer );

		//compute channel for triggerring other user to perform computation
		computeChannel = session.createChannel(client, computeChannelName,true,
true, true);
		computeChannelConsumer  = new ComputeChannelConsumer() ;
		computeChannel.addConsumer(client, computeChannelConsumer );

		//BC channel for managing the BC
		bcChannel = session.createChannel(client, bcChannelName,true,true,true);
		bcChannelConsumer  = new BCChannelConsumer() ;
		bcChannel.addConsumer(client, bcChannelConsumer );

		//Point force channel takes care of issues related to point force
		pointForceChannel = session.createChannel(client,
pointForceChannelName,true,true,true);
		pointForceChannelConsumer = new PointForceChannelConsumer() ;
		pointForceChannel.addConsumer(client, pointForceChannelConsumer );

		//visualization channel takes care of issues about visualization
		visualizationChannel = session.createChannel(client,
visualizationChannelName,true,true,true);
		visualizationChannelConsumer  = new VisualizationChannelConsumer() ;
		visualizationChannel.addConsumer(client, visualizationChannelConsumer );

		//fileUnit channel takes care of issues about input new geometric files and
unit problems
		fileUnitChannel = session.createChannel(client,
fileUnitChannelName,true,true,true);
		fileUnitChannelConsumer = new FileUnitChannelConsumer() ;
		fileUnitChannel.addConsumer(client, fileUnitChannelConsumer );

		//fileUnit channel takes care of issues about input new geometric files and
unit problems
		zoomChannel = session.createChannel(client,
zoomChannelName,true,true,true);
		zoomChannelConsumer = new ZoomChannelConsumer();
```

```
            zoomChannel.addConsumer(client, zoomChannelConsumer );

            distributedChannel = session.createChannel(client,
distributedChannelName,true,true,true);
            distributedChannelConsumer = new DistributedChannelConsumer();
            distributedChannel.addConsumer(client, distributedChannelConsumer );

            //Monitor the behavior of users
            zoomChannel.addChannelListener(new ChannelConsumerListener() );

            //Create a mouse token
            mouseToken = session.createToken(client, mouseTokenName, true);
            //Attention the mouseToken is used in MouseRotateNetwork class
            newUserToken = session.createToken(client, newUserTokenName, true);

            updateMemberList();

            try
            {
              //Cooonection is a jsdt class
              Connection.addConnectionListener(serverName,
sessionImplementationType, new FailureConnectionListener());
            }
            catch(JSDTException e)
            {
              System.out.println("Coundn't add connectionListener"+e);
            }

            connected = true;
          }
        } catch (Exception e) {
          System.out.println("Fea3DUser.connect: "+e);
        }
      } catch (Throwable th) {
        System.err.println("Fea3DUser: connect caught: " + th);
        throw new Error("Fea3DUser.connect failed : " + th);
      }
    }

    //****************************************
    final public void disconnect() {
      if (connected == false) {
        return;
      }

      try {
```

```
        //If this is the last client of the group, we need to destroy the generalChannel
        //which is created for this patricular group
        String[] clientList = generalChannel.listClientNames();
        if (clientList.length ==1)
        generalChannel.destroy(client);
        session.close(true);

    } catch (Exception e) {
        System.err.println("Caught exception while trying to " +
        "disconnect from sun3D server: " + e);
        if (Fea3DUser_Debug) {
            e.printStackTrace();
        }
    }
    connected = false;
}

//****************************************
//The method is used to send data
//****************************************
public final  void sendObjects(Object obj, int id)
{
    if ( connected == false | DataContainer.generalToolBar.collaborative == false)
    {
        return ;
    }

    try {
        //long start = System.currentTimeMillis();
        Data data = new Data(obj);
        data.setPriority(Channel.HIGH_PRIORITY);
        switch(id)
        {
            case GENERAL:
        { generalChannel.sendToOthers(client, data); break;}
            case MESH:
        { meshChannel.sendToOthers(client, data); break;}
            case CHATROOM:
        { chatChannel.sendToAll(client, data); break;}
            case BC :
        { bcChannel.sendToOthers(client, data); break ;}
            case POINT_FORCE :
        { pointForceChannel.sendToOthers(client, data) ;break ;}
            case COMPUTE :
        {computeChannel.sendToOthers(client, data); break ;}
            case VISUALIZATION :
```

```
    {visualizationChannel.sendToOthers(client,data); break; }
      case FILE_UNIT:
    {fileUnitChannel.sendToOthers(client,data);break;}
      case ZOOM:
    {zoomChannel.sendToOthers(client,data);break;}
      case DISTRIBUTED_FORCE:
    {distributedChannel.sendToOthers(client, data) ; break;}
      default:
    {break;}
    }

    data = null;
    //long end = System.currentTimeMillis();
    //System.out.println("sending time ="+(end-start) );
  } catch (ConnectionException ce) {
    System.out.println("Fea3DUser:  exception: " + ce);
    disconnect();
  } catch (TimedOutException ce) {
    System.out.println("Fea3DUser: exception: " + ce);
    disconnect();
  } catch (Exception e) {
    e.printStackTrace();
  }
}//end of sendObjectToOthers()

public void removeConsumers()
{
  try
  {
    if ( newUserToken.test() == Token.GRABBED)
    {
      newUserToken.release(client);
    }

    //mouseToken.release(client);
  }
  catch(JSDTException e)
  {
    //System.out.println("Failed in releasing token."+e) ;
  }

  //disconnect from other users
  try
  {
    generalChannel.removeConsumer(client, generalChannelConsumer );
    meshChannel.removeConsumer(client, meshChannelConsumer);
```

```
        chatChannel.removeConsumer(client, chatChannelConsumer );
        computeChannel.removeConsumer(client, computeChannelConsumer );
        bcChannel.removeConsumer(client, bcChannelConsumer );
        pointForceChannel.removeConsumer(client, pointForceChannelConsumer );
        visualizationChannel.removeConsumer(client, visualizationChannelConsumer );
        fileUnitChannel.removeConsumer(client, fileUnitChannelConsumer );
        zoomChannel.removeConsumer(client, zoomChannelConsumer );
        distributedChannel.removeConsumer(client, distributedChannelConsumer);
    }
    catch (JSDTException e)
    {
        e.printStackTrace();
    }
}

public void addConsumers()
{
    //disconnect from other users
    try
    {
        generalChannel.addConsumer(client, generalChannelConsumer );
        meshChannel.addConsumer(client, meshChannelConsumer);
        chatChannel.addConsumer(client, chatChannelConsumer );
        computeChannel.addConsumer(client, computeChannelConsumer );
        bcChannel.addConsumer(client, bcChannelConsumer );
        pointForceChannel.addConsumer(client, pointForceChannelConsumer );
        visualizationChannel.addConsumer(client, visualizationChannelConsumer );
        fileUnitChannel.addConsumer(client, fileUnitChannelConsumer );
        zoomChannel.addConsumer(client, zoomChannelConsumer );
        distributedChannel.addConsumer(client, distributedChannelConsumer);
    }
    catch (JSDTException e)
    {
        e.printStackTrace();
    }
}

//Join again
public void join()
{
    try
    {
        session.join(client) ;
        System.out.println("Successful in joining the session") ;
    }
    catch(JSDTException e)
```

```
    {
      System.out.println("Failed in joining the session"+e) ;
    }
}

//****************************************
//The method is used to send data
//****************************************
public final  void sendToNewClient(String receivingClientName, Object obj, int id)
{
   if ( connected == false | DataContainer.generalToolBar.collaborative == false)
   {
      return ;
   }

   try {
      //long start = System.currentTimeMillis();
      Data data = new Data(obj);
      data.setPriority(Channel.HIGH_PRIORITY);
      switch(id)
      {
         case MESH:
      { meshChannel.sendToClient(client, receivingClientName, data); break;}
         case BC:
      { bcChannel.sendToOthers(client, data); break ;}
         case POINT_FORCE :
      { pointForceChannel.sendToClient(client, receivingClientName, data) ;break ;}
         case COMPUTE :
      {computeChannel.sendToClient(client, receivingClientName, data); break ;}
         case VISUALIZATION :
      {visualizationChannel.sendToClient(client, receivingClientName, data); break; }
         case FILE_UNIT:
      {fileUnitChannel.sendToClient(client, receivingClientName, data);break;}
         case DISTRIBUTED_FORCE:
      {distributedChannel.sendToClient(client, receivingClientName, data) ; break;}
         default:
      {break;}
      }
      data = null;
      //long end = System.currentTimeMillis();
      //System.out.println("sending time ="+(end-start) );
   } catch (ConnectionException ce) {
      System.out.println("Fea3DUser:  exception: " + ce);
      disconnect();
   } catch (TimedOutException ce) {
      System.out.println("Fea3DUser: exception: " + ce);
```

```
            disconnect();
        } catch (Exception e) {
            e.printStackTrace();
        }
    }//end of sendObjectToOthers()

    public void updateMemberList()
    {
        updateMemberList(null);
    }

    public void updateMemberList(String receivingClient)
    {
        try {
            //Here we need to list the client names on the left area
            String[] clientNames = generalChannel.listClientNames();
            String clients = "Team account:\n"+teamName+"\nTeam members:";
            for ( int i = 0 ; i < clientNames.length ; i++)
            {
                if ( "Server".equals(clientNames[i]) | clientNames[i].equals(receivingClient) )
                {
                    //do nothing
                }
                else
                {
                    clients = clients+"\n"+clientNames[i];
                }
            }
            DataContainer.teamMembersBoard.setText(clients);
            //++++++++++++++++++++++++++++
        }
        catch(JSDTException e)
        {
            System.out.println("Coundn't get the clientNames list"+e);
        }
    }


    public void clearMemberList()
    {
     DataContainer.teamMembersBoard.setText(null);
    }
}
```

Appendix F: Java 3D for the Engineering Analysis

```
//**************************
// Copyright Qiuli Sun August 2001
// The University of Oklahoma
//**************************
/**
This is a main program which works as a 3D data viewer.
The program runs as an applet. The Java shared Data Toolkit
is also integrated in this client application. Another application
needs to run on the server in order to communicate between users.
 */

package edu.ou.eml.fea3d;

import edu.ou.eml.fea3d.layout.*;
import edu.ou.eml.fea3d.collaboration.*;
import edu.ou.eml.fea3d.interaction.*;
import edu.ou.eml.fea3d.mesh.*;
import edu.ou.eml.fea3d.data.*;
import edu.ou.eml.fea3d.force.*;
import edu.ou.eml.fea3d.misc.*;
import edu.ou.eml.fea3d.solver.*;


//****Standard import *********
import java.applet.Applet;
import java.awt.*;
import java.awt.event.*;
import com.sun.j3d.utils.geometry.*;
import com.sun.j3d.utils.universe.*;
import javax.media.j3d.*;
import javax.vecmath.*;
import javax.swing.*;
import java.net.*;
import java.io.*;
import java.util.*;
import javax.media.j3d.View;
import javax.swing.border.*;
import javax.swing.Timer;
import com.sun.j3d.utils.applet.MainFrame;

//------------------------------------------------------------------------------------------
public class Fea3D extends JApplet implements ActionListener, Runnable
{
```

```
    private static flnal float FRONT_RATE = 0.2f;
    private static final float BACK_RATE = 50.0f ;
    public static final float EYE_RATE = 1.9f;

    JButton pStartButton;
    URL pText3DFile = null;
    URLConnection conn = null;
    Thread p3DThread;
    JFrame baseFrame = null;
    static ProgressMonitor pMonitor;
    static int pProgress;
    SceneGraph pSceneGraph;
    View pView;
    Insets pInserts;
    EtchedBorder pBorder;
    Appearance pMaterialAppear;
    WireframeGeometry pWireframeGeometry = null;
    CoordinateSystem coordSystem ;

    public ReadGeometryData readTool;

    public void init()
    {
      initializeJava3D();
      pInserts = new  Insets(0,1,0,1);
      pBorder = new EtchedBorder(EtchedBorder.LOWERED);
      pStartButton = new JButton("3D FEA");
      pStartButton.setMargin(pInserts);
      pStartButton.setFont(new Font("SanSerf",Font.PLAIN,13));
      pStartButton.addActionListener(this);
      this.getContentPane().add(pStartButton);
      try {
UIManager.setLookAndFeel(UIManager.getCrossPlatformLookAndFeelClassName());
      } catch (Exception e){
        System.err.println("Can't set look and feel:"+e);
      }

      //It is extremely important to place pMonitor here
      Component parent = (Component)pStartButton;
      pMonitor = new ProgressMonitor(parent, "Loading Progress",
      "Getting Started to render...", 0, 100);
      pMonitor.setMillisToDecideToPopup(100);
      setStartProgress(0);

      //For debugging, please don't delete it
```

```
        pText3DFile = Fea3DFactory.getURL(Fea3D.this, "retainingWall.txt");

        //pText3DFile =  null;

        readTool = new ReadGeometryData();
        readTool.setURL(pText3DFile);
        //pass the reference into DataContainer
        DataContainer.setReadTool(readTool);

        //JPopupMenu.setDefaultLightWeightPopupEnabled(false);
        //ToolTipManager.sharedInstance().setLightWeightPopupEnabled(false);

//System.out.println("lw="+ToolTipManager.sharedInstance().isLightWeightPopupEnabl
ed());

        //initializeNetwork();
    }

    //**************************
    private void initializeJava3D()
    {
        //Initialize the basic data
        DataContainer dataContainer = new DataContainer();

        p3DThread = new Thread(this);
        p3DThread.setPriority(Thread.MAX_PRIORITY);

        pMaterialAppear = new Appearance();
        pMaterialAppear.setCapability(Appearance.ALLOW_MATERIAL_WRITE);
        pMaterialAppear.setMaterial(DataContainer.material);
        pWireframeGeometry = new WireframeGeometry();

        //Manage the hidden lines
        //Create a DataContainer.hiddenShape3D
        HiddenLineManager hiddenLineManager = new HiddenLineManager() ;
    }

    //*****************************
    private void initializeNetwork()
    {
        DataContainer.serverName = this.getCodeBase().getHost() ;
        String userName = this.getParameter("userName");
        String newChannelName = this.getParameter("NEWCHANNEL");

        //====================================
        //This is only for testing. They should be redesigned later
```

```
    //=====================================
    if (newChannelName == null | userName == null )
    {
      newChannelName = "guestGroup";
      userName = "guest"+ (Fea3DFactory.randomRange (0, 500)
      * Fea3DFactory.randomRange (0, 500)) ;
    }
    else
    {
      //This is to make user everyone log in as guest, the multi-user
      //still works
      if ( "guestGroup".equals(newChannelName) & "guest".equals(userName) )
      {
        userName = "guest"+ (Fea3DFactory.randomRange (0, 500)
        * Fea3DFactory.randomRange (0, 500)) ;
      }
    }

    DataContainer.newChannelName = newChannelName ;
    DataContainer.userName = userName ;

    //=====================================

    System.out.println("team name = "+newChannelName);
    System.out.println("user name = "+userName);

    //Fea3D must be initialized here since it needs
    //DataContainer.newChannelName being set first
    DataContainer.fea3DUser = new Fea3DUser ();
    try
    {
      DataContainer.fea3DUser.connect();
    }
    catch(Exception e)
    {
      System.out.println("Connection failed");
    }
  }
  //*************** End of initializing ************

  public void run()
  {
    URL iconURL;
    Dimension myButtonSize = new Dimension(32,26);
    pStartButton.setEnabled(false);
    baseFrame = new JFrame("Collaborative 3D Finite Element Analysis");
```

```
//Record baseFrame in the DataContainer for easy access of other classes
DataContainer.setFrameBase(baseFrame);

WindowListener  winListener = new FrameWindowAdapter();
baseFrame.addWindowListener(winListener);

Container contentPane = baseFrame.getContentPane();
//Layout must be set, otherwise confused
contentPane.setLayout(new BorderLayout());
//Create a general tool bar
GeneralToolBar generalToolBar = new GeneralToolBar(Fea3D.this);
DataContainer.generalToolBar = generalToolBar ;

ToggleToolBar toggleToolBar = new ToggleToolBar(Fea3D.this);

SouthPane southPane = new SouthPane(Fea3D.this);

contentPane.add(generalToolBar, BorderLayout.NORTH);
contentPane.add(toggleToolBar, BorderLayout.WEST);
contentPane.add(southPane, BorderLayout.SOUTH);

baseFrame.setSize(510,590);

setStartProgress(20);

//Update the Data in the DataContainer
if (DataContainer.updateGeometricData() == false)
{
  //InitializeAppletStatus();
}
else
{
  DataContainer.geometry =  this.getGeometry();
}
setStartProgress(40);

GraphicsConfiguration config = SimpleUniverse.getPreferredConfiguration();
Canvas3D canvas3D = new Canvas3D(config);
DataContainer.canvas3D = canvas3D ;

contentPane.add(canvas3D, BorderLayout.CENTER);
coordSystem = new CoordinateSystem();

setStartProgress(70);
```

```
    // Create a simple scene and attach it to the virtual universe
    pSceneGraph = new SceneGraph(true, DataContainer.shape3D,
DataContainer.geometry,
    pMaterialAppear, DataContainer.geometryTG, canvas3D);
    BranchGroup scene = pSceneGraph.createSceneGraph();

    SimpleUniverse u = new SimpleUniverse(canvas3D);
    DataContainer.universe = u ;

    initializeNetwork();
    setStartProgress(90);

    // This will move the ViewPlatform back a bit so the
    // objects in the scene can be viewed.

    u.setJ3DThreadPriority(Thread.MAX_PRIORITY - 1);

    u.getViewingPlatform().setNominalViewingTransform();
    pView = u.getViewer().getView();

    pView.setFrontClipDistance(DataContainer.maxXYZ*FRONT_RATE);
    pView.setBackClipDistance(DataContainer.maxXYZ*BACK_RATE);
    zoomInOut(EYE_RATE);

    u.addBranchGraph(scene);
    setStartProgress(100);
    pMonitor.close();
    baseFrame.setVisible(true);

  } // end of run()

  //*****************************************************
  private void setStartProgress(int pProgress)
  {
    pMonitor.setProgress(pProgress);
    pMonitor.setNote("loaded "+ pProgress+"%");
  }
  //*****************************************************
  private void InitializeAppletStatus()
  {
    // System.out.println("There is no 3D information in the data files or the file doesn't
exist!");
    JOptionPane.showMessageDialog(
    DataContainer.baseFrame,
    "There is no 3D information in the\n"
    +"data files or the file doesn't exist!",
```

```
    "Boundary Condition Warning Message",
    JOptionPane.WARNING_MESSAGE);
    System.gc();
  }
  //*****************************************************
  public void actionPerformed(ActionEvent e)
  {
    Object source = e.getSource();
    if(source==pStartButton && baseFrame==null)
    {
      p3DThread.start();
    }
    if(source==pStartButton && baseFrame!=null)
    {
      baseFrame.setVisible(true);
    }
  }

  //*****************************************************
  private synchronized GeometryInfo processGeometryData()
  {
    GeometryInfo gi = new GeometryInfo(GeometryInfo.POLYGON_ARRAY);
    gi.setCoordinates(DataContainer.points);
    gi.setCoordinateIndices(DataContainer.polyPointsIndex);
    gi.setStripCounts(DataContainer.pStripCounts);

    Triangulator tr = new Triangulator();
    tr.triangulate(gi);
    gi.recomputeIndices();

    NormalGenerator ng = new NormalGenerator();
    ng.setCreaseAngle(2.01*Math.PI/14.0);
    ng.generateNormals(gi);
    gi.recomputeIndices();

    Stripifier st = new Stripifier();
    st.stripify(gi);
    gi.recomputeIndices();
    //release the memory
    tr = null;
    ng = null;
    st = null;
    return gi;
  }

  //**********************
```

```
public void update()  {
   if (ImportActionListener.pText3DFile ==null) return;

   System.out.println("Updating ......");
   //Release the memory before updating
   DataContainer.points = null;
   DataContainer.pStripCounts = null;
   DataContainer.polyPointsIndex = null;

   if (DataContainer.updateGeometricData() == false)
   {
      InitializeAppletStatus();
   }
   else
   {
      DataContainer.geometry = Fea3D.this.getGeometry();

      //Always update the view volume
      pView.setFrontClipDistance(DataContainer.maxXYZ*FRONT_RATE);
      pView.setBackClipDistance(DataContainer.maxXYZ*BACK_RATE);
      zoomInOut(EYE_RATE) ;
      DataContainer.shape3D.setGeometry(DataContainer.geometry);

      updateCoordSystem() ;
      //delete everything
      DeleteActionListener.delete() ;
   }
}

//My own WindowAdapter
private class FrameWindowAdapter extends WindowAdapter
{
   FrameWindowAdapter()
   {
      super();
   }
   public void windowClosing(WindowEvent e){
      pStartButton.setEnabled(true);
   }
}
//******************************
// We must disconnect the applet
//******************************
public void destroy()
{
   DataContainer.fea3DUser.disconnect();
```

```
    }

    private IndexedGeometryArray getGeometry()
    {
      pWireframeGeometry.setGeometryInfo (
      DataContainer.points,
      DataContainer.pIDPT1,
      DataContainer.pIDPT2 ) ;
      return  pWireframeGeometry.getWireframeGeometry();
    }

    void updateCoordSystem()
    {
      //We need to delete the previous one
      for (int  i = 0 ; i < DataContainer.geometryTG.numChildren (); i++)
      {
        if ( DataContainer.geometryTG.getChild (i) == coordSystem.coordSystemBG )
        {
          //Remove the coord from the scene graph
          DataContainer.geometryTG.removeChild (i);
          break;
        }
      }//end of for()
      //create a new one
      coordSystem = new CoordinateSystem() ;
    }

    //Other class will call these two methods
    public static void zoomInOut(float zoomRate)
    {
      Transform3D pEyePoint = new Transform3D();
      pEyePoint.setTranslation(new Vector3f ( 0.0f, 0.0f, DataContainer.maxXYZ *
zoomRate ) );
      TransformGroup pViewPlatformTG =
      DataContainer.universe.getViewingPlatform().getViewPlatformTransform();
      pViewPlatformTG.setTransform(pEyePoint);
    }

    public static void undoZoom()
    {
      zoomInOut(EYE_RATE) ;
    }

} //end of Japplet
```

Appendix G: Perl Script for the VRML Structure

```
#soil.pl

read(STDIN, $buffer, $ENV{'CONTENT_LENGTH'});

$mainFolder = "vcity";

# split name and value into pairs
@nvpairs = split(/&/, $buffer);

# single > writes file (even if existing)  >> appends file
$pair1 = @nvpairs[0];
($Dname, $DirVolName) = split(/=/, $pair1);

$pair2 = @nvpairs[1];
($fname, $wrlfilename) = split(/=/, $pair2);

# sets dam height
$pair3 = @nvpairs[2];
($bname, $damBottom) = split(/=/, $pair3);

# sets dam left
$pair4 = @nvpairs[3];
($bname, $damLeft) = split(/=/, $pair4);

# sets dam top
$pair5 = @nvpairs[4];
($bname, $damTop) = split(/=/, $pair5);

#sets dam height
$pair6 = @nvpairs[5];
($bname, $damHeight) = split(/=/, $pair6);

        # to check the value to make sure no strange data
if ($damBottom < 20.0)
  { $damBottom = 20.0;}
if ($damLeft < 5.0) {$damLeft = 5.0;}
if ($damTop < 5.0) {$damTop = 5.0;}
if ($damHeight < 5.0) {$damHeight = 5.0;}
$damRight = $damBottom - $damLeft - $damTop;
if ($damRight<5.0) {$damRight = 5.0;}
```

```
######################################
$halfBottom = 0.5*$damBottom;
$negativeHalfBottom = -1.0*$halfBottom;

$halfTop = 0.5*$damTop;
$left = $halfBottom - $damLeft;
$negativeLeft = -1.0*$left;

$right = $halfBottom - $damRight;
$negativeRight = -1.0*$right;

$FullPathWrl =">".$mainFolder."/users/".$DirVolName."/dam.wrl";
open(INFO, $FullPathWrl);

print INFO <<endfile;
#VRML V2.0 utf8

#Cosmo Worlds V2.0

Transform {
 children      [
      Shape {
  appearance  Appearance {
   material    Material {
      ambientIntensity      0.162791
      diffuseColor   0.35 0.41 0.43
      specularColor  0.15 0.17 0.18
      emissiveColor  0.14 0.16 0.17
      shininess      0.32
      transparency   0
   }

  }

  geometry    DEF dam_0 IndexedFaceSet {
   coord      Coordinate {
      point   [
                220 0 $halfBottom,
                -220 0 $halfBottom,
                -220 0 $negativeHalfBottom,
                220 0  $negativeHalfBottom,
                220 $damHeight $negativeRight,
                220 $damHeight $left,
                -220 $damHeight $left,
                -220 $damHeight $negativeRight
 ]
```

```
    }

   color        Color {
       color   [ 0 1 0,
                0.1 1 0.3,
                0 1 0,
                0 1 0,
                0 1 0,
                0.8 1 0 ]
    }

    coordIndex          [ 0, 1, 2, 3, -1, 0, 3, 4,
               5, -1, 3, 2, 7, 4, -1, 2,
               1, 6, 7, -1, 0, 5, 6, 1,
               -1, 4, 7, 6, 5, -1 ]
    colorPerVertex    FALSE
    solid         TRUE
    normalIndex         [ ]
    texCoordIndex     [ ]
   }

  }
]
 translation    420 0 -300
}

endfile


close(INFO);
```

Appendix H: ASP Script with SQL Statements

```
<%@Language="VBSCRIPT" %>

<% Option Explicit
Response.Buffer = true
Dim curUserID, curPassword
Dim Connect,onAccount,onGroup,SQL,SQL1,StartTime,logSQL
Dim teamID, cookieFlag, groupID

' if cookieFlag = 1, we use Personal web server,
'otherwise, cookieFlag = 0

cookieFlag = 0

teamID =  Request.Form("teamID")
groupID = Request.cookies("groupID")

Set Connect = Server.CreateObject("ADODB.Connection")
Connect.Open "DSN=vcity","sa",""
StartTime = CStr(Now)

IF groupID = "" Then
    Response.Redirect("../error/group_id_error.htm")
End if

IF teamID="" Then
   curUserID = Request.Form("userID")
   curPassword = Request.Form("password")
'************************
'check if the password and userID is correct
'************************
  Set onAccount = server.CreateObject("ADODB.Recordset")
         'Guest can log in any group
         IF curUserID <> "guest" then
    SQL = "select * from userAccount where userID = '"&curUserID&_
    "'"&" and password ='"&curPassword&"'"&" and groupID = '"&groupID&"';"
         ELSE
           SQL = "select * from userAccount where userID = '"&curUserID&_
    "'"&" and password ='"&curPassword&"';"
         END IF
  onAccount.Open SQL,Connect

  If onAccount.BOF=true  Then
   Response.Redirect("../error/id_error.htm")
```

```
        'Response.write(curUserID)
        'Response.write(curPassword)
 Else
   Response.Cookies("dir") = Request.Form("userID")

        If cookieFlag =1 Then
          Response.Cookies("dir").Expires = #12/30/2001#
        End If

        logSQL = "insert into sessionLogInfo(eventDateTime,eventType,"_
       &"userAccountID,sessionID,userIPAddress,numberOfHits,userAgent) values('"_
       &startTime&"',"_
       &"'New Session',"_
       &"'"&curUserID&"',"_
       &session.sessionID&","_
       &"'"&Request.ServerVariables("REMOTE_ADDR")&"',"_
       &"0"&","_
       &"'"&Request.ServerVariables("HTTP_USER-Agent")&"')"

       Response.write(logSQL)

       insertDatabase(logSQL)

       Session.Contents("AccountID")=curUserID

  Response.Redirect("checkCookie.asp")
 End if
Else
 curUserID = Request.Form("individualID")
 curPassword = Request.Form("gpassword")
 IF curUserID <> "guest" THEN
        SQL = "select * from userAccount where userID = '"&curUserID&_
   "'"&" and password ='"&curPassword&"'"&" and groupID = '"&groupID&"';"
 ELSE
        SQL = "select * from userAccount where userID = '"&curUserID&_
  "'"&" and password ='"&curPassword&"';"
 END IF
       Set onAccount = Connect.Execute(SQL)

       'We should check if the user has already registered in one group city

       SQL1= "select * from teamMembers where teamID = '"&teamID&_
 "'"&" and memberID ='"&curUserID&"';"
       Set onGroup = Connect.Execute(SQL1)

       If onAccount.BOF = true or onGroup.BOF=true Then
```

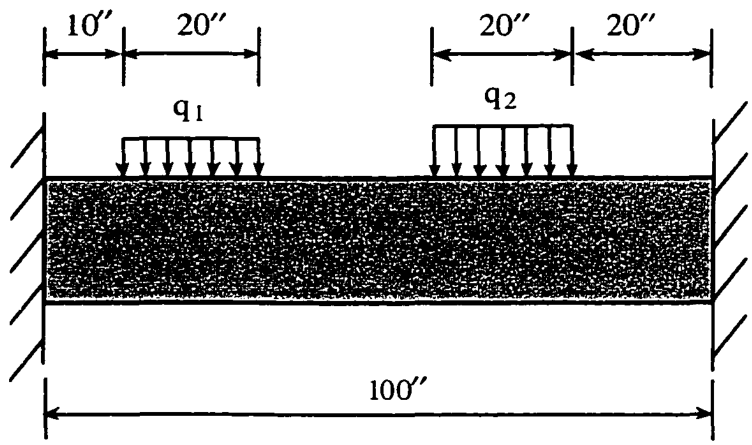
```
        Response.Redirect("../error/id_error.htm")
          Else
             Response.Cookies("dir") =  Request.Form("teamID")
                   Response.Cookies("teamMember") =Request.Form("individualID")

                   If cookieFlag =1 then
               Response.Cookies("dir").Expires = #12/30/2001#
                          Response.Cookies("teamMember").Expires = #12/30/2001#
             End If

                   logSQL = "insert into sessionLogInfo(eventDateTime,eventType,"_
          &"userAccountID,sessionID,userIPAddress,numberOfHits,userAgent) values('"_
          &startTime&"',"_
          &"'New Session',"_
          &"'"&curUserID&"',"_
          &session.sessionID&","_
          &"'"&Request.ServerVariables("REMOTE_ADDR")&"',"_
          &"0"&","_
          &"'"&Request.ServerVariables("HTTP_USER-Agent")&"')"

          Session.Contents("AccountID")=curUserID

          insertDatabase(logSQL)

                 Response.Redirect("checkCookie.asp")
          End If

End If

'************************
'Set the value of the cookie and check if
' the user supports cookies

'************************
' Set the log information into the database
'***********************
'***************** write to the database functions
Sub insertDatabase(SQL)
  Dim Connect
  Set Connect = Server.CreateObject("ADODB.Connection")
        Connect.Open "DSN=vcity","sa",""
        Connect.Execute(SQL)
        Connect.Close
        Set Connect = Nothing
End Sub
%>
```

Appendix I: Homework Assignment of the Third Survey

AME 4193 Spring 2001
Homework assignment
Assigned: Thursday, April 19, 2001
Due: 9:00a.m., Tuesday, May 1, 2001

Requirements: **Each group only needs to submit one copy of homework. Each member should submit a copy of the individual surveying form. Group members must work jointly on the homework.**

Design a beam with minimum weight using the geometrical modeling module and the engineering analysis module. Material is steel, and its properties are: $E = 29.0\times10^6\ psi$, $\nu = 0.32$, unit weight = $0.284\ lb/in^3$, yield stress = $36\times10^3\ psi$ and safety factor = 1.5. The length of the beam, boundary condition, and forces are as follows. $q_1 = -1000\ lb/in$, $q_2 = -1500 lb/in$.



(a) Design a rectangular cross section of the above beam with minimum weight subject to stress using the geometric modeling module.
(b) Conduct FEA using the engineering analysis module and make sure the maximum von Mises stress is less than the allowable stress. Use tetra element and brick element with coarse meshing.
(c) Use tetra element and brick element with fine meshing.
(d) Try at least three cross sections and obtain the best valid cross section.

Please note the pressure is used in engineering analysis module. Therefore q_1 *and* q_2 **should be converted into the pressure.**

Qiuli Sun's office is Room 235, Felgar Hall. He will be available most of the time. Also, he will be in the CAD lab on April 29, 30 from 8:00pm to 11:30pm to help you use his Virtual City.

Appendix J: Survey Questions of the Third Survey

Surveying Form

AME 4193, Spring 2001, Date: April 19, 2001

Strongly agree = 1 Agree = 2 No opinion = 3 Disagree = 4 Strongly disagree = 5	
1. It is helpful if geographically distributed engineers can work in a well-designed collaborative design environment.	1 2 3 4 5
2. The Internet should be used for collaborating engineering design and analysis.	1 2 3 4 5
3. A collaborative design environment encourages spirit of teamwork when it is used to complete homework jointly.	1 2 3 4 5
4. A collaborative design environment encourages collaborative learning of remote users.	1 2 3 4 5
5. The engineering analysis module is good at helping you better visualize stresses and displacements.	1 2 3 4 5
6. The Virtual City is good at presenting the big picture and 3D visualization.	1 2 3 4 5
7. Internet-based engineering education with capabilities of 3D engineering design and analysis will be popular in five years.	1 2 3 4 5
8. It helped to collaborate online using the design environment for the homework.	1 2 3 4 5
9. It was easy to use the distributed collaborative design environment.	1 2 3 4 5
10. It was helpful to see a 3D stress state while designing the beam.	1 2 3 4 5

11. What features would you expect for a distributed collaborative design environment?

12. What are the typical behaviors of the group members in a collaborative environment?

13. Comments

Appendix K: Opinions about the Implemented Technologies

Multiple Internet technologies were used to conduct the research of the Virtual City, including HTML, JavaScript, Shockwave, VRML, Java, Java 3D, ASP, SQL, Perl, and MS SQL Server. These technologies can be grouped into client-side and server-side technologies. They have different advantages and limitations. With the introduction of new technologies and the change of the technological trends, initial choices may not be the best anymore.

The client-side technologies contains HTML, JavaScript, Shockwave, VRML, Java, Java 3D. HTML is good at formatting texts, and its quality is acceptable. However, it is difficult to use HTML to display complex mathematical equations. Pixel-based images are therefore utilized to display these equations, but it particularly difficult to edit them. In the future research, Extensible Markup Language (XML) may be considered. JavaScript is useful to add client-side interactivity to HTML pages. For example, a number of pieces of information can be contained in a cookie, and the cookie allows information to be transferred from one page to another. But, this strategy will not work if the user disables the cookie in the browser. In this case, server-side strategies may be more appropriate. VRML was popular to demo 3D objects over the Internet, and its text-based file is easy to understand. Few companies, however, are pushing this technology currently. Hence, it becomes more and more difficult to find the updated plug-in for VRML. Shockwave can be utilized to program graphic-oriented simulations. It is easy to learn and there is no plug-in issue since the plug-in can be downloaded automatically with the permission of the user. It has a built-in scripting language called Lingo, but it is a challenge to program large complex applications with Lingo since it is not a structured general-purpose programming language. Java is a powerful object-oriented general-purpose programming language. Its networking capabilities make it a good choice for collaborative applications. Microsoft has, however, stopped to support Java, and a Java plug-in is necessary for Web-based Java applets. Also, if extensions of Java are used, the user needs to download these extensions separately. This is extremely inconvenient for the user.

The server-side technologies include ASP, SQL, Perl, and MS SQL Server. ASP is a Microsoft solution to the server-side interactivity. It works seamlessly with Microsoft Internet Information Server (MS IIS). The biggest concern with MS IIS is its security since numerous viruses are currently attacking MS IIS. Perl is a free scripting language to add the server-side interactivity. It can work with any operating systems, such as Windows, Unix, and Macintosh. One problem with Perl is that it may need some skills to make it work on the server. SQL is a friendly query language, and it is an international standard. It can work smoothly with ASP and Perl to access the database. It is a good choice to employ SQL to manipulate the database. MS SQL Server is a medium-side relational database, which can store a larger amount of data than Access. But, it is more difficult to manage the data in MS SQL Server than in Access.

Since each technologies takes time to learn, if similar concepts need to implement again it may be wise to use only HTML, JavaScript, Shockwave, ASP, SQL, and MS SQL Server. This is because the latest version of Shockwave has already supported 3D and there is no need to utilize VRML, Java, and Java 3D to implement 3D visualization. ASP can perform the same function as Perl so that the user does not need to learn Perl.