Using Expert Systems Technology to Teach Earthquake Resistant Design of Buildings

Abbes Berrais
Abha College of Technology, POB 238, Abha, Saudi Arabia

Abstract

Computers have been introduced as an element into the teaching environment for a long time now. Until recently, computers have been used for relatively routine calculations such as: report writing, spreadsheets, drafting, and simple simulations. Very rarely are computers used to help teach and visualize fundamental concepts, or to explore the alternative solutions of a design project. Today the most interesting and exciting branch in computer applications is expert systems technology. Expert system technology can play a great role in enhancing the processes of teaching and learning in engineering education.

This paper addresses the impact of Expert Systems (ES) technology in providing the necessary support for developing earthquake engineering computer-aided education. An introduction to ES technology is briefly presented. Then, the benefits from the application of ES in engineering education are outlined. A theoretical strategy is proposed for developing ES prototypes for engineering education purposes. An educational prototype ES for teaching earthquake resistant design of buildings is briefly presented. The prototype was developed using a SUN SPARCstation under the UNIX operating system, and using Quintec-Prolog, Quintec-Flex, and FORTRAN 77 as programming environment. The paper concludes with a summary and recommendations on future impact of artificial intelligence and ES technologies on computer-aided engineering education.

1. Introduction

Computers have been introduced as an element into the teaching environment for a long time now. Until recently, computers have been used for relatively routine calculations such as: report writing, spreadsheets, drafting, and simple simulations. Very rarely are computers used to help teach and visualize fundamental concepts, or to explore the alternative solutions of a design project[1]. The integration of computers in higher education is still minimal in subjects that require symbolic reasoning such as designs problems. The nature of civil engineering problems is known to be complex, three-dimensional, and dynamic. Solutions to these problems require the use of advanced computer technologies for complex mathematical simulation, computation, communication, and manipulation and storage of data. Educating a student in a specific subject requires techniques in directing the learning process to the best output of the student. Computer-aided education tools are required to assist students in learning how to perform practical design problems and how to perform “What-If” design scenarios[2]. To fulfill these requirements, universities and colleges should incorporate special courses on “computer-aided engineering education” which are aimed at the application of computers to solve engineering problems. This proposal is intended to help students to learn and get experience more quickly compared to, for example, using conventional techniques (such as Books and Blackboard). A combination of theory with software applications is recommended in elementary courses. Students should learn the basic computing skills and computerized structural and design methods.

Programs which could be considered to be used to support the learning process include: artificial intelligence & expert system applications designed for teaching engineering methods: such as statics, mechanics, structural analysis, and design; World Wide Web techniques and multi-media; softwares for visualization of engineering problems; and laboratory testing with computer simulations. The software must be easy to use and should provide an interactive user-interface to facilitate the learning process of the students. This could be achieved by Artificial Intelligence (AI) techniques such as Expert Systems[3] (ES).

This paper addresses the impact of ES technology in providing the necessary support for developing civil engineering computer-aided education. An introduction to ES technology is briefly presented. Then, the theoretical background of a strategy is presented for the development of ES for the support of the learning and training processes of students. A prototype educational ES, which helps and assists students during the preliminary earthquake analysis and design of buildings, is briefly presented. The prototype was developed using a SPARCstation under the UNIX operating system and using Quintec-Prolog, Quintec-Flex, and FORTRAN 77 as programming environment. The paper concludes with a summary and recommendations on the future impact of AI and ES technologies on computer-aided engineering education.

2. Expert Systems Technology in Engineering Education

ES technology is one of the branches of artificial intelligence research to date. Gasching *et al*[4] have defined ES as: "*An ES is an interactive computer program incorporating judgment, human experience, rules of thumb, intuition, and other expertise to provide knowledgeable advice about a variety of tasks*". ES have been developed to solve many types of problems in different areas such as medicine, geology, and engineering. ES can be developed using different AI programming tools[5]: programming languages (such as Prolog, Lisp, C), expert system shells, and programming environments. ES are playing a great role in helping to solve problems that require knowledge and engineering judgment.

ES technology could play a supportive role in engineering education, unfortunately it is not fully benefited from the sector of education in universities. ES technology can facilitate the transfer of engineering knowledge and educational expertise from humans to computers, and can explain this knowledge to students. The teacher will get used to acquire knowledge from books and human experts and encode them into computer compatible format. The aim of ES techniques in structural engineering is to give the student an opportunity to do the analysis and design of a structural system by using, for example, FEM techniques in a simplified way. Students learn how to analyze and design buildings and obtain the moments, shear and reinforcement results for different structural elements. In this case the student is learning by doing. The problems solved should be simple so that the student could progress in the learning process.

ES can help students to participate during the learning process, and to ask questions related to a specific subject. This is known as “active learning experiences”. ES can help establish the link between symbolic concepts and engineering problems. In addition, ES can help students in the formulation of problems, in the selection of the best engineering solution from a set of alternatives, and in the critiquing the solution. Therefore, the student will learn by doing, thereby providing a motivational ingredient to the learning environment. The teacher could play the role of an intermediary between the student and the ES, and he will help students interact with the ES and to interfere as necessary.

Computer usage should be incorporated early in the university curriculum in order to provide students with the skills necessary to tackle challenging problems in their future careers. Computational techniques with engineering principles should be included early in the student educational process. There are no restrictions on the suitable areas for engineering applications of ES, but in general, areas that are characterized with symbolic reasoning and require explanation are more suitable for ES application. Subjects such as: Conceptual Design, Preliminary and Detailed Design could be considered as suitable civil engineering areas for ES applications. ES technology can assist in the effective teaching and learning processes and the quality of educational experiences can be enhanced for both the student and the teacher. In addition, ES technology can provide the student with the opportunity to explore and be more creative during the engineering design process.

3. Modern Approach to Computer-Aided Engineering Education

The traditional use of computers to train students is limited to the input data for programs and obtains some results[6,7]. The student who deduces the conclusions analyzes the results. With this type of approach, the programs represent a fixed set of knowledge and information that the student cannot contribute in their development or interact with them. In addition, this approach used in teaching design has become increasingly less effective as the requirements and complexity of design practice have increased, especially regarding the use of computers in engineering. Furthermore existing computer-aided training do not provide advice custom-tailored for a specific student[8,9]. Whereas with ES technology, the student can interact with the program and can collaborate in the solution of the problem, resulting in a higher motivation in his learning. This new approach is illustrated in Figure 1. With this approach, there is a mutual interaction between the student, the ES and the teacher.

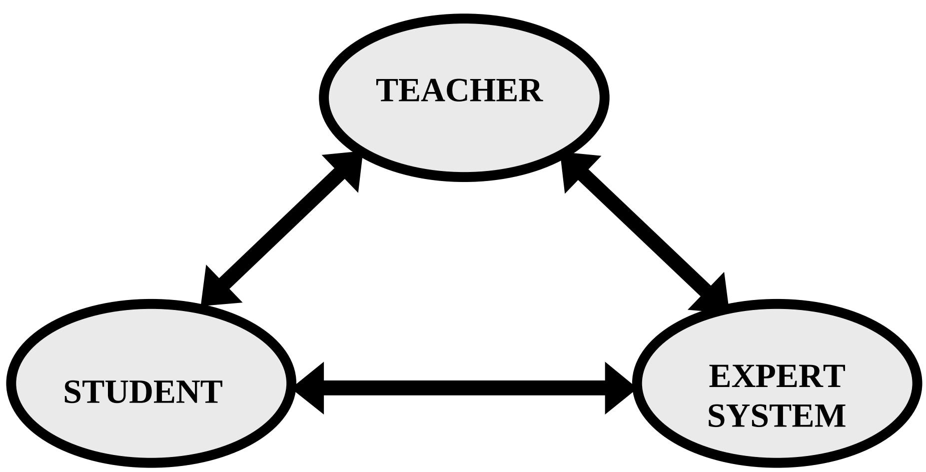

Figure 1: Modern approach to computer-aided education *(after Souto et al 1990)*

Vanegas[10] proposed a computer educational framework to support the requirements of a senior design capstone course for construction engineering and management students. He recommends the use of the computer as a natural partner throughout the learning process, and developing the student’s familiarity with basic tools and understanding of basic approaches in: numerical computation, graphics, and information technology. In this way, students will develop the ability and understanding to integrate sophisticated computerized tools and techniques in their future professional practice to maximize productivity. Additionally, the coupling of ES and conventional techniques will provide integrated computer-aided educational systems, and therefore will enhance the learning process of student.

With ES, the student can observe the knowledge and the line of reasoning of the program. An ES would have many advantages over conventional on-line instructional systems. ES store information in an active form called Knowledge Base, rather than in a passive form such as textbooks. This knowledge can be kept up-to-date more easily and be consulted at any time. An Es could be used to create a teacher-monitor that is not subject to human failing like fatigue. ES can be used to preserve engineering knowledge that might be lost. The student should not only know the theoretical background of the computer tools but also be familiar with the associated numerical methods and their limitations[11]. There is a strong demand to teach computational techniques in an integrated way. Preferably theory, numerical methods and use of computers should be combined in one course. For this purpose special software tools, such as ES technology, are needed to support the learning process by cutting down complex applications into sub-tasks.

4. Computational Teaching Requirements

Research and development of computer-based education is an extremely lengthily process which requires appropriate people and funding[12]. The interactive computer program should perform several educational functions, thus facilitating an effective teaching-learning process. In other words, the computer program should provide or facilitate the transfer of teaching materials (e.g. engineering theories) into interactive computer programs. It has to be recognized that no matter how 'intelligent' computers are they cannot be substituted for the personal contact between the teacher and the student. The aim is to build computer-aided education programs that can closely imitate the interaction between the teacher and student.

The basic ingredients for teaching engineering computational techniques are the theoretical framework and its mathematical background as well as numerical methods. For example, for a student to learn the theory of elasticity, he might use the finite element method to solve any complicated problem. For the understanding of the method, the student needs a background of matrix algebra. For this purpose computer techniques should encourage students to investigate different methods and solution procedures and to get a good visualization of the obtained results. Exercises in the courses should be chosen such that students recognize practical applications.

Pudlowski[12] suggested some specific requirements for computer-aided education programs as follows:

- training should be as individualized as possible so student can be allocated to particular courses in accordance with his needs;
- training should be conducted in a logical order;
- the question and answer type teaching strategy should be enriched, thereby enhancing the level of interaction;
- lessons or instruction should complement the work of the teacher;
- designed materials may be easily reviewed and updated at any time;
- the program should be able to work in a computer network.

5. Prototype Example

The proposed educational ES prototype, which is called EDA (Earthquake Design Assistant), is a teaching tool for helping civil engineering students to carry out the earthquake analysis and design of reinforced concrete building. The knowledge representations used in EDA include *clauses* and *facts*, *production rules*, *frames* and *data driven procedures*, these being provided by Quintec-Prolog[13] and Quintec-Flex[14]. The numerically intensive procedures are represented in FORTRAN 77 as external programs.

The EDA is designed to:

- Assist the student in checking the regularity requirements of a building according to the UBC[15] code;
- Estimate the different earthquake design factors using the UBC lateral static force code method; and
- Model and perform the elastic and inelastic analysis of the building

The EDA architecture is shown in Figure 2. The EDA architecture has the following components:

- *Knowledge base* : comprises of several engineering knowledge modules. Each module is responsible for a specific engineering task.
- *Context* (working memory): contains the collection of facts that represent the current state of the problem in hand.
- *Inference Mechanism*: controls the system by modifying and updating the context using the knowledge in the knowledge base.
- *Explanation facility*: provides the student with the necessary explanations about the task being performed.
- *Student-interface*: provides a channel through which the student can interact with the modules of EDA. The Student interface of EDA is shown in Figure 3.

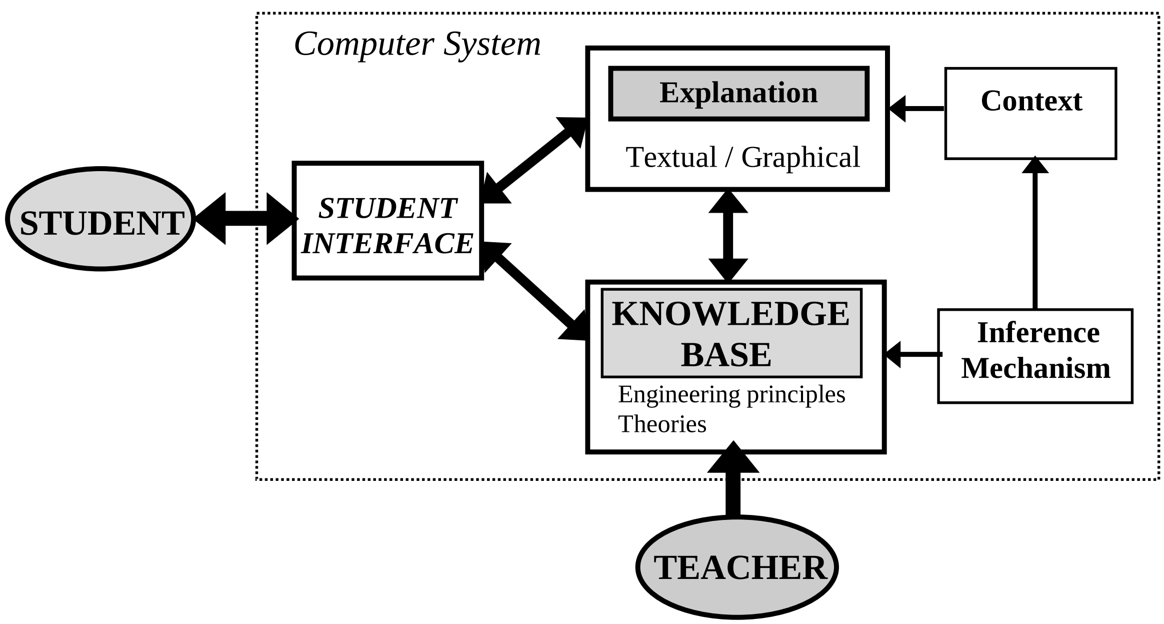

Figure 2: Architecture of the educational expert system EDA

Student-Interface

The student-interface is the most critical component of an educational expert system, and is a necessity for the success and acceptability of any expert system. The design of the student-interface is influenced by many factors, amongst these[16] : the cognitive model of the student's thought processes, aspects of usability, the type and capabilities of the programming tools, the hardware environment, and the intended function of the ES. The general screen display (Master Menu) of the EDA student-interface is shown in Figure 3. The student errors were identified and classified into two categories: computing errors, and engineering task errors. Computing errors are concerned with system commands and functions, whereas engineering task errors are concerned with engineering tasks such as: earthquake theories, analysis techniques, and design procedures.

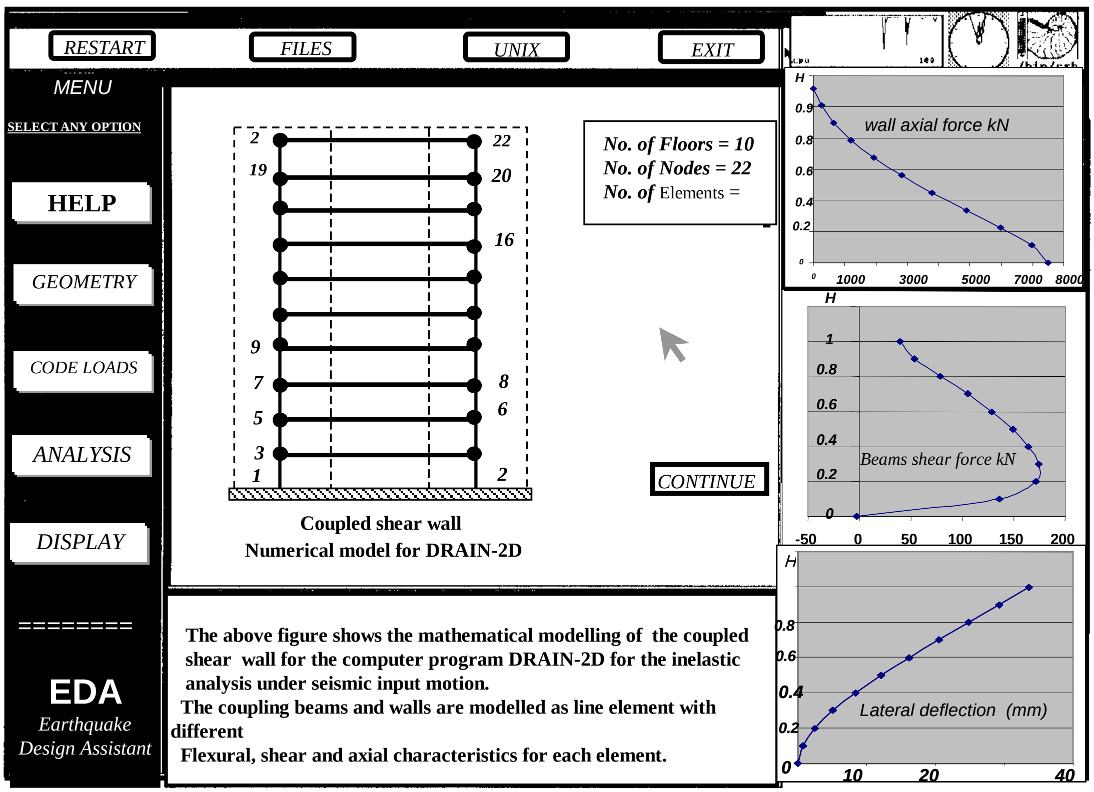

Figure 3. User interface of the EDA system

Student-interface Menus

The Master Menu is divided into five windows as shown in Fig. 3. The top and left-hand windows are used for the high-level options that contain all the major functions (of EDA). The large window in the middle is the main input/output window where the dialogue between the student and EDA is carried out. The right hand side window is a graphical window that deals with the graphical explanation. The bottom window is a message/warning window that displays warnings about unusual actions by the student. The high-level options are divided into two types based on their function (see Fig. 3): *Engineering options* on the left side and

S*ystem* options across the top. These options are described briefly below:

Engineering options:

Engineering options are concerned with the engineering capabilities of the EDA system:
HELP: provides help on earthquake design terminology and engineering background information.
GEOMETRY CHECK: concerned with building eccentricity requirements.
CODE LOADS: concerned with evaluating the code base-static shear forces.
ANALYSIS: concerned with the modeling and elastic/inelastic analysis of RC buildings.
DISPLAY: concerned with the graphical and textual display of design information.

System options:

System options are concerned with tasks related to the management of the system:
RESTART: clears the windows and return the student to the first display in a defined sequence.
FILES: concerned with the management of data and system files.
UNIX: gives temporary access to UNIX operating system.
EXIT: to exit EDA completely.

The philosophy behind using these different menu options is that the student can have the opportunity to initiate EDA at any level of abstraction he wishes with some degree of control on EDA behavior. Menu displays are beneficial because they always display the possible range of commands, research has shown[17] that humans are much better at recognizing a correct choice rather than recalling that choice from memory.

6. Explanation Facility

The ability of the ES to provide an explanation to its reasoning is an important aspect of its intelligibility and acceptability to the student. The explanation offered by the EDA system includes: 'Why' and 'How' types with deep explanation about a specific engineering task. This can be activated by an *Explain* or *More Details* button associated with the textual window of the required engineering task. The utility of this is that the student will have more understanding of the meaning of different engineering terms and relations used by EDA. In addition, EDA maintains a record of the decision it makes. It uses this record to explain and justify its decisions and conclusions on request.

7. Conclusion

This paper highlighted the importance of the application of AI and ES technologies in civil engineering education. ES technology is a powerful tool for storing and manipulating large amount of engineering educational knowledge and expertise to be used by students. It can efficiently improve and facilitate the use of engineering theories and computer programs. ES is considered as a supportive tool for the teacher. Such technology could free the teacher from the more tedious aspects of engineering education and other duties, and allow him to devote more effort and time to the creative side of teaching. There is a need for more innovative and intelligent tutoring systems for educational purposes. Teachers should experiment with ES shells for building their own systems in their different specialties. The use of computer-generated lectures using ES technology will enable students to visualize linkages between theory, mathematical models and physical systems. Furthermore, the student is capable of interacting with the ES and can collaborate in the solution of the problem, resulting in a higher motivation in student's learning. ES technology can very easily be integrated with existing conventional educational softwares to provide robust educational systems.

An educational ES prototype in the area of earthquake analysis and design of buildings has been briefly described. The main objective of developing EDA is to enhance the student understanding and learning of earthquake resistant design of buildings. The prototype is easy to use and does not require a lot of efforts from the student. The achievements of the EDA prototype include:

- The provision of engineering assistance to students in civil engineering area and expose them to difficult level of complexity and integration in the solution of earthquake design problems;
- Reduction in the learning time for students, and thus reduced the time the teacher needs to devote to the program use;
- Enabling the effective use of complex analysis and design methods, including interpretation of the analysis results; and
- Strengthening existing civil engineering teaching methods, and provide teacher and students with powerful tools to increase the breadth and complexity of the problem addressed and solved in the class, thus expanding their earthquake engineering knowledge.

Bibliography

1. Lennox, W. C. and Wills, B. L., Encouraging Faculty Participation in the Exploration of Instructional Computer Technologies: An Organizational Model, in *Computer Aided Training in Science and Technology*, Proceedings of the International Conference on Computer Aided Training in Science and Technology, (E. Onate et al. Eds.), Barcelona 9-13 July, Centro International de Metodos Numericos en Ingenieria, 1990, 120-126.
2. Gramoll, K. C., GT Beam **-** An Interactive Graphic Beam Analysis Program for Education, *Computing in Civil and Building Engineering*, Proceedings of the Fifth International Conference (V-ICCCBE), ASCE, California, 1993, 455-461.
3. Siekmann, J., Lecture Notes in Artificial Intelligence, Artificial Intelligence in Higher Education, CEPES-UNESCO International Symposium, Prague, CSFR, October 1989 Proceedings, Springer-Verlag, 1990.
4. Gasching, J., Reboh, R. and Reiter, J., "Development of a Knowledge-Based System for Water Resource Problems". SRI Project Report 1629, SRI international, August 1982.
5. Adeli, H. (1988), *Expert Systems in Construction and Structural Engineering*, Chapman and Hall, London, UK.
6. Souto, J. A. and Rodriguez, A., Prolog-Based Expert System for CAT in Chemical Engineering, in *Computer Aided Training in Science and Technology*, Proceedings of the International Conference on Computer Aided Training in Science and Technology, (E. Onate et al. Eds.), Barcelona 9-13 July, Centro International de Metodos Numericos en Ingenieria, 1990, 557-563.
7. Kuhn, M. R., and Inan, M. I., Early Integration of Computational Methods in the Engineering Curriculum, *Computer Utilization in Structural Engineering*,, (ed. James K. Nelson), ASCE, 1989.
8. Areitio, M. G., The Natural Evolution Step for the CAT: The Expert System, *in Computer Aided Training in Science and Technology*, Proceedings of the International Conference on Computer Aided Training in Science and Technology, (E. Onate et al. Eds.), Barcelona 9-13 July, Centro International de Metodos Numericos en Ingenieria, 1990, 148-153.
9. Henry, R. J., Role of Advanced Computer Technology in construction Industry, *Journal of Computing in Civil Engineering*, 1994, 8(3), 385-389.
10. Vanegas, J. A., An Integrated Computer- Based Total Design Environment for Civil Engineering

Education, *Computing in Civil and Building Engineering*, Proceedings of the Fifth International Conference (V-ICCCBE), ASCE, California, 1993, 439-446.

11. Wriggers, P., Stein, E. and Miehe, C., The Impact of Computer Aided Teaching in Lecturing Computational Mechanics, *in Computer Aided Training in Science and Technology*, Proceedings of the International Conference on Computer Aided Training in Science and Technology, (E. Onate et al. Eds.), Barcelona 9-13 July, Centro International de Metodos Numericos en Ingenieria, 1990, 24-33.
12. Pudlowski, J., Developing Computer Program for Engineering Education - Important Issues, *in Computer Aided Training in Science and Technology*, Proceedings of the International Conference on Computer Aided Training in Science and Technology, (E. Onate et al. Eds.), Barcelona 9-13 July, Centro International de Metodos Numericos en Ingenieria, 1990, 34-41.
13. Quintec System Ltd., *QUINTEC-PROLOG*, System Predicates, Unix version, UK, 1989.
14. Quintec System Ltd., *QUINTEC-FLEX*, User Manual, Unix version, UK, 1989.
15. International Conference of Building Officials, ICBO (1991), UBC:91, *Uniform Building Code*, Whittier, CA.
16. Berrais, A., Knowledge-Based Expert Systems: User Interface Implications, *Journal of Advances in Engineering Softwares*, 1997, 28(1), 31-41.
17. Majchrzak A., and Tien-Chien Chang *et al.*, *Human Aspects of Computer-Aided Design*, Taylor & Francis Ltd, 1987.

ABBES BERRAIS
Abbes Berrais is an Assistant Professor of Computer-Aided Structral Engineering at Abha College of Technology, Saudi Arabia. He received his B.Sc(Eng) degree in Civil Engineering, from Algiers University in 1985, M.Sc(Eng) in Structural Engineering from Liverpool University, UK, in 1988, and a Ph.D from the Civil Engineering Department at Leeds University, UK, 1992.