Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte

Band: 68 (1993)

Artikel: Expert system for maintenance of timber warren trusses

Autor: Akhras, Georges / Foo, Simon H.C.

DOI: https://doi.org/10.5169/seals-51863

Expert System for Maintenance of Timber Warren Trusses

Système expert pour l'entretien de poutres triangulées en bois

Expertensystem für den Unterhalt von Holzfachwerken

Georges AKHRAS
Associate Professor
Royal Military College
Kingston, ON, Canada

Georges Akhras is Assoc. Prof. of Civil Eng. For 10 years he was a project manager for computer applications and numerical analysis in government and industry, before joining RMC in 1987.

Simon H.C. FOO
Research Engineer
Royal Military College
Kingston, ON, Canada

Simon Foo is Research Eng. of Civil Eng. He received his PhD degree in 1985 at the Univ. of Ottawa His research interests are expert systems, reinforced concrete and timber structures and bridges.

SUMMARY

This paper describes the design and the development of a knowledge-based expert system for the maintenance of timber Warren trusses. These trusses, constructed during World War II, have deteriorated over the years and require repair. In order to properly maintain these buildings, regular inspection by engineers to assess their structural and service conditions is required. A knowledge-based expert system is being developed to aid the engineers, experienced or novice, in conducting an inspection of the trusses. The system integrates the concepts of expert systems, object-oriented programming, relational database and graphics.

RÉSUMÉ

La détérioration due au vieillissement de nombreuses poutres triangulées en bois, du type ferme Warren, construites au cours de la seconde guerre mondiale, exige des travaux de réparation. En vue d'assurer l'entretien convenable des immeubles concernés, les ingénieurs doivent effectuer des inspections régulières des poutres triangulées et déduire leur état d'utilisation. Le système expert élaboré à cet effet doit permettre d'aider les ingénieurs - expérimentés ou novices - dans le déroulement des inspections des éléments porteurs triangulés. Ce système intègre les concepts d'un système expert, une programmation à orientation objet, une banque de données relationnelles et l'infographie.

ZUSAMMENFASSUNG

Im Zweiten Weltkrieg entstanden Holzfachwerke des Warren-Typs, deren Alterung über die Jahre hinweg Instandsetzungsarbeiten erfordert. Für den ordentlichen Unterhalt der betreffenden Gebäude sind regelmässige Inspektionen des Tragwerks und der Nutzungsverhältnisse durch Ingenieure nötig. Das entwickelte Expertensystem soll die Ingenieure - ob erfahren oder nicht - bei der Durchführung der Fachwerkinspektionen unterstützen. Das System integriert die Konzepte von Expertensystem, objektorientierter Programmierung, relationaler Datenbank und Computergraphik.

1. BACKGROUND

1.1 The Structure

The Department of National Defence of Canada (DND) owns many hangar type timber Warren truss buildings on Canadian Forces bases. These buildings, built during and soon after World War II to meet the needs of the expanded Armed Forces establishment, were constructed as temporary structures and were used mainly by the military for aircraft housing and maintenance. Although these buildings were labelled "temporary", it is estimated that there are more than two hundred of them still in service across Canada [1].

Two standardized truss configurations were used in these buildings : an eight-panel pitched chord Warren truss and a seven-panel parallel chord Warren truss, both with a span length of 34.14 m (112 ft). A typical building has eleven trusses spaced at 4.88 m (16 ft). Many of the buildings using the parallel chord truss configuration were constructed with two rows of trusses connected by a line of central columns.

Elevation and plan views of a typical double parallel building are given in Fig. 1. Panel and truss spacings both equal to 4.88 m (16 ft). Although overall configurations of the trusses were standardized using Douglas Fir of selected structural grade, individual details may vary from building to building. Primary variations occurred in the vertical struts and bracing members. The post-tensioning cables as shown in Fig. 1 were not included in the original design and construction. They were installed and used as a strengthening system to release member forces after some members have been found to be subjected to stresses beyond their design strengths.

1.2 The Problem

Because of the large and urgent demand of timber for so many buildings of this size, timber of below specified grade were used for some buildings. Within the first few years of service and after the timber dried out, the trusses began to show signs of distress due to shrinkage. The resulting structural deficiencies included cracking and splitting of truss or splice members, fracture of truss members, excessive deformation and loss of camber. These structural deficiencies were soon recognized and a program of rehabilitation, repair and reinforcement was established. To avoid inconsistent results and to eliminate considerable duplication of effort, DND published the Construction Engineering Technical Order, or CETO [1], which outlined the guidelines and direction for the assessment, repair and maintenance procedures of all DND timber Warren truss buildings.

For the maintenance of these timber Warren truss buildings, CETO recommends that an inspection be performed on these trusses on an annual basis. Condition survey of these timber buildings are usually carried out by military engineers from 1 CEU (1 Construction Engineering Unit). 1 CEU has a limited number of military engineers, most of whom spend about four or more months in the field conducting inspection of timber trusses. It is also DND's policy that military personnel be posted elsewhere every three to four years. This policy leads to a perpetual shortage of experienced engineers who are familiar with the inspection and repair procedures.

Because of the huge inventory of aging buildings and a small number of experienced engineers with the necessary expertise, at times, methods of rehabilitation appear to be more practically available than competent engineers. Extensive consultation is often required to reach an appropriate decision regarding the inspection results as well as the repair solutions.

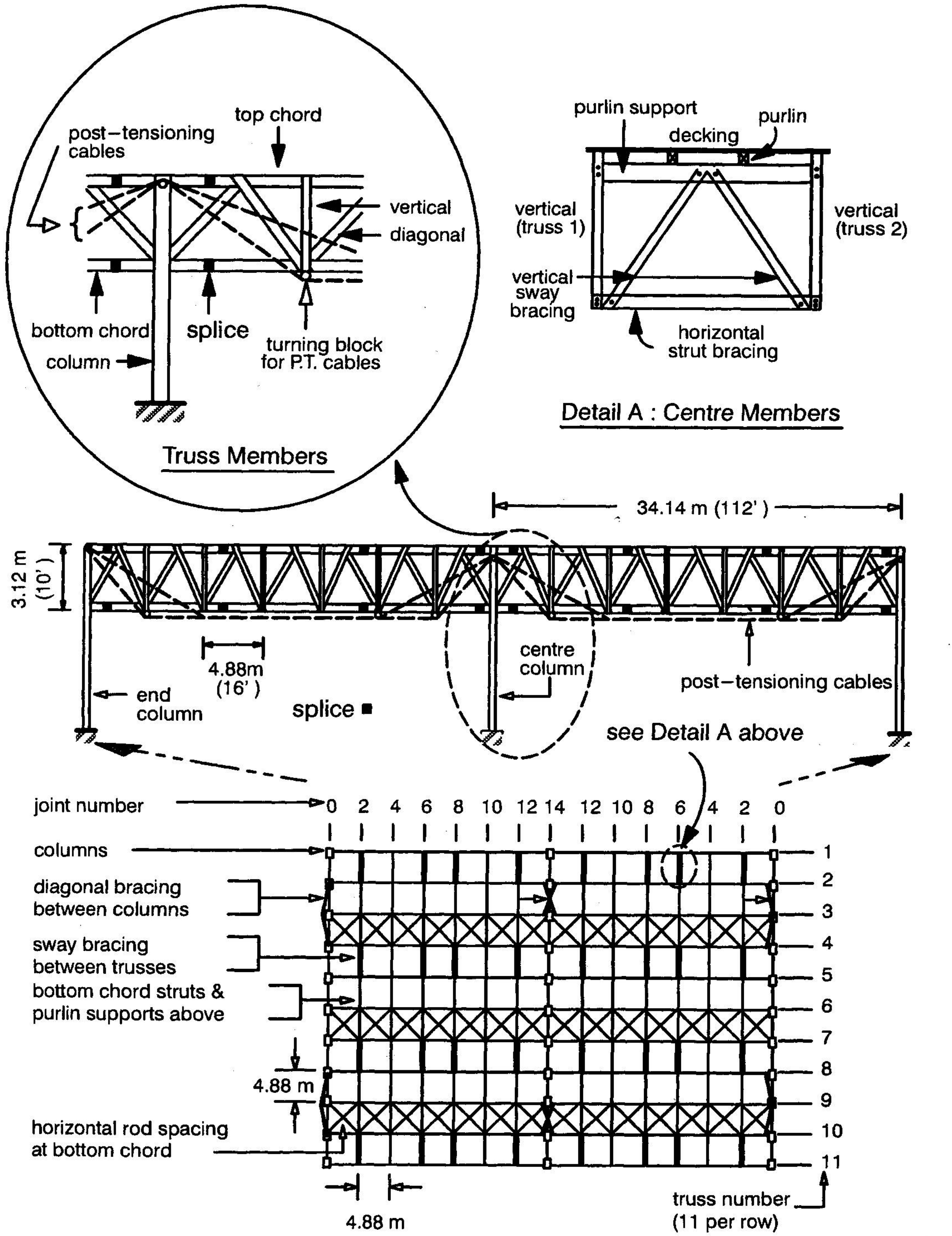


Fig. 1 A double parallel chord Warren truss building

1.3 The Expert System Approach

A method of transferring knowledge from the timber truss inspection experts to less experienced or local inspection personnel is required. An expert system, also known as knowledge-based expert system (KBES), is a computer program which captures human knowledge and decision making processes. Fully developed KBESs are capable of accepting facts from the user, processing these facts against the knowledge base, and on the basis of these facts and knowledge, delivering solutions which are close to the solutions by a human expert.

Primary benefits of using a KBES include reliability (increased possibility of correct and consistent decisions) and productivity (improved efficiency). KBESs can be used as training and education tools for both practising engineers and university students. From the DND's point of view, potential benefits of an expert system application also include the elimination or reduction of such common problems as the lack of trained personnel, the vacuum created during military posting and the time spent in retraining staff.

An object-oriented system is being developed by the KBES group of the Civil Engineering at the Royal Military College of Canada for the overall maintenance of these buildings [2,3]. The system has four knowledge bases : inspection/repair, database management, structural analysis and upgrading of buildings to meet the latest building code. This paper presents the strategies and techniques used in the development of the first two knowledge bases, i.e. inspection/repair and database management. They integrate the concepts of knowledge-base system, object-oriented programming, relational database and hypermedia paradigm in a windowing environment. Illustrative sample sessions are given to demonstrate the capabilities of the system.

2. INSPECTION OF TIMBER WARREN TRUSS

Each truss comprises of truss members, post-tensioning cables and columns as shown in Fig. 1. There are also centre members that exist between neighbouring trusses, including roof deck, purlins and purlin supports. Brief description of the function of each building component is given in CETO.

Typical problems which individual building components may encounter as well as the reinforcing schemes adapted to repair these components are distinctively different from each other. As an example, Fig. 2 lists the possible causes of defect that should be checked when conducting an inspection of a top chord. Appropriate action required to repair these members would depend upon the type of deficiencies that best describe the existing conditions of the member. For example, if split/check found in a top chord is less than 0.5 mm wide, no repair is deemed necessary. If, however, the member has been found to have split/check extended to edge of the member, it needs to be replaced by using the procedures outlined in CETO. Other methods of repair include replacing cracked splice block, installing gusset plates at deteriorated joint and the use of steel shims between top chord and splice connection.

3. OBJECT-ORIENTED EXPERT SYSTEMS

An expert system has two basic components: a knowledge base and an inference engine which is also the control structure of the system. The knowledge obtained from the human expert or experts comprises information specific to the domain of the problem being addressed and is

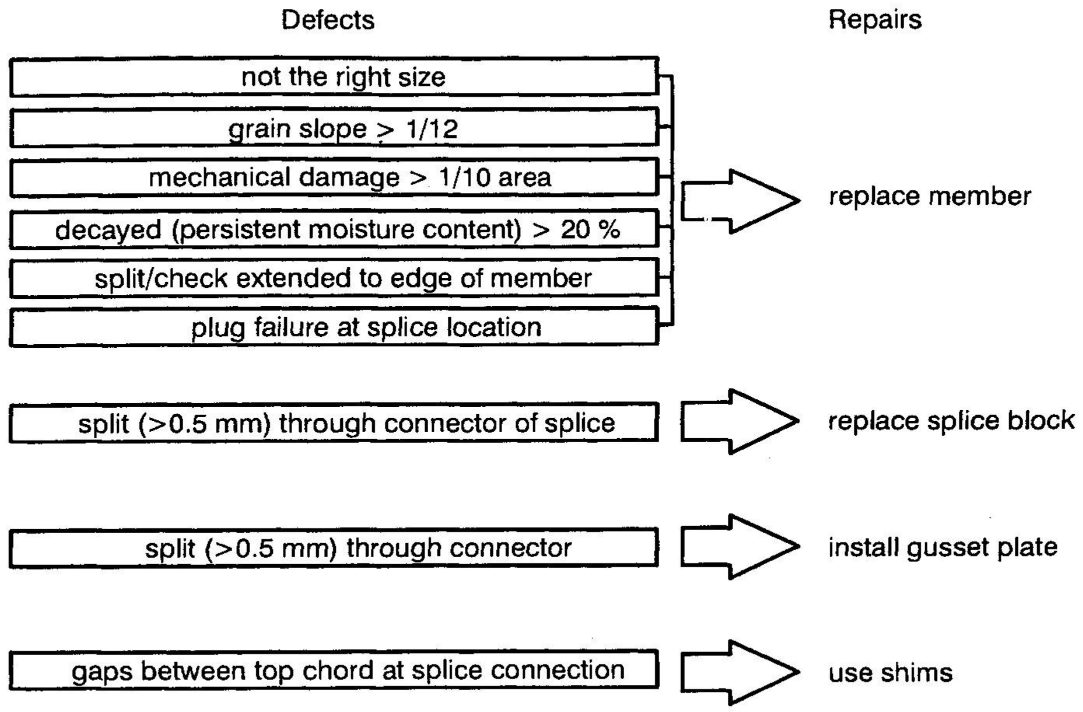


Fig. 2 Inspection consideration for top chord

captured in the knowledge base. The inference engine interprets and applies the knowledge base and attempts to make decisions to problems that would ordinarily require a human expert.

The heart of any expert systems is the knowledge base, which is usually a collection of rules, typically in the form of 'IF...AND..OR...THEN...AND..ELSE..'. If the antecedent of a rule (IF...AND..OR...) is found to be true, the inference engine fires the rule, inferring the 'THEN...AND...' statement(s). There are other components which the knowledge base may be constructed of, such as frames, nets, and more recently object-oriented approach. Because of its modularity, data abstraction and inheritance characteristics, object-oriented programming or OOP, will likely subsume other approaches in the very near future.

In an object-oriented environment, objects represent the properties of a data structure and the operations permitted and performed on the structure. In other words, an object is the sum of its data and procedures and performs operations on itself [4,5,6]. The five key words in OOP are object, class, instance, method and message [7].

A class describes the structure and behaviour of an object within an application and is defined by a collection of characteristics called attributes. An instance is a specific occurrence of an object. Methods are procedures associated with an attribute that can determine the attribute's value or execute a series of procedures when the attribute's value changes. Message is used to invoke operations of an object or among objects. Fig. 3 shows the tree structure of an object used by Level5 Object [4], which is one of the many commercially available software for object-oriented expert system development.

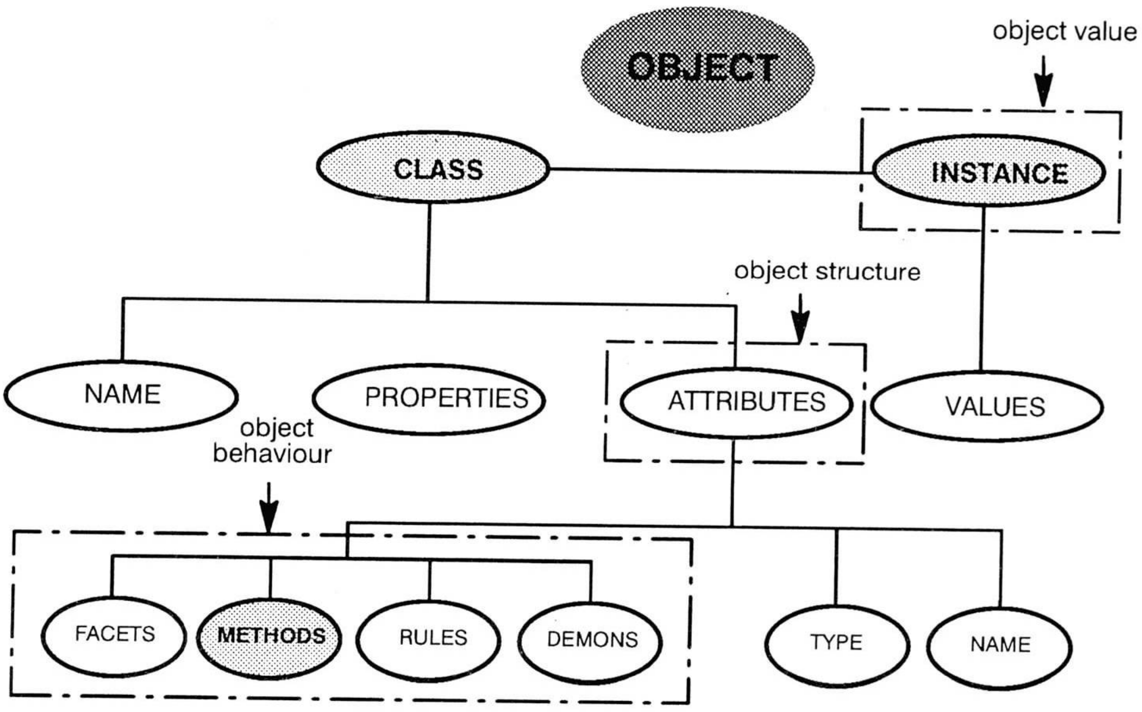
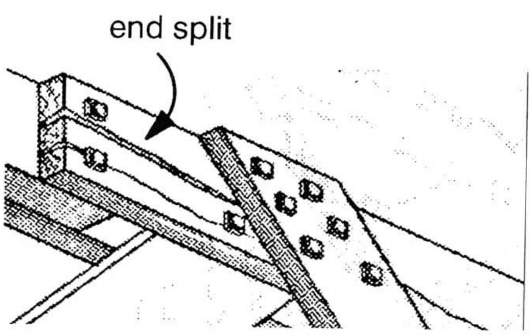


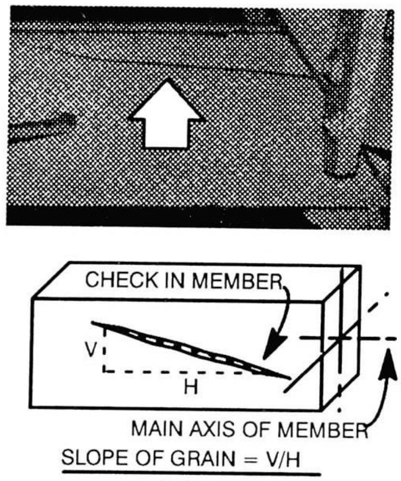
Fig. 3 Defining an object

The object orientation is particular evident in a new class of programming environments that are based on graphical objects rather than text listings. For example, the key feature of the typical information-handling problem encountered during an inspection is the correct interpretation of visual images. To reduce the dependency on subjective judgement and to improve the consistency in decision making, a diagnostic KBES with graphical representation of knowledge is very useful.

An object-oriented system can display implicit knowledge by means of real graphic images as shown in Fig. 4. Fig. 4a depicts an example of an end split. Fig. 4b illustrates an example of split/check and demonstrates how to measure the slope of grain.



(a)



(b)

Fig. 4 Graphical representation of knowledge

4. AN OBJECT-ORIENTED SYSTEM FOR WARREN TRUSS INSPECTION

4.1 System Description

An expert system is being developed for the condition survey of timber Warren trusses. The expert system provides advice to inspectors concerning how to identify deficiencies in the condition evaluation process. The system can also be used as a tutorial for inexperienced inspectors.

The knowledge is drawn mainly from CETO [1] and partially from engineers of 1 CEU. The expert system is being developed on an IBM-compatible personal computer, using an object-oriented shell program [8] in a windowing environment. The system being developed is highly user friendly with many graphics-oriented interface features such as interactive graphics, window management, explanation expansion and graphical representation of knowledge base by mapping graphic displays to and from conclusions.

User help screens are important for both the acceptance and efficient use of KBESs by the user community. They also enhance the use of the system as a training tool. The system has an efficient explanatory component to make the comprehension and checking of how a solution is reached possible and effective. The explanatory facility of the system can be used as an aid for novice engineers to learn, with or without the manuals, more about the inspection process.

User interface plays a major role in the acceptance of any system by its end users. Since the system has graphical user interface with explanatory facilities, little or no programming knowledge and experience is required to use the system. Users simply point and click his/her way through the inspection process to appreciate the dynamic behaviour of the system.

4.2 Example

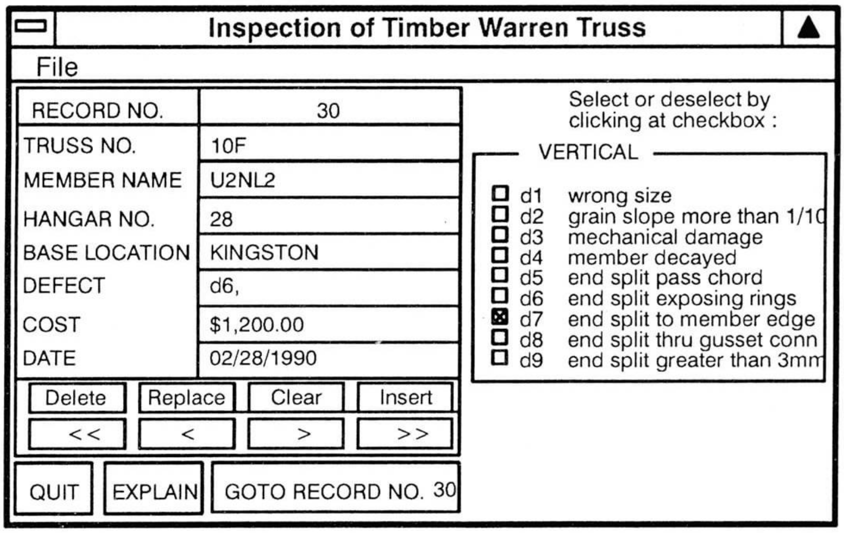
Fig. 5a and 5b illustrate the typical screen images from a sample session when conducting an inspection of a particular truss member. Half of Fig. 5a is devoted to information display and to available database function keys. Member identification and location are drawn from a database. The user can use the database function keys to delete, replace, clear or insert the current record, or to edit the first (<<), previous (<), next (>) or the last (>>) record of the database.

A list of nine (9) possible defects is given in the other half of Fig. 5a in a checkbox form. Clicking on "Explain" pushbutton in Fig. 5a directs the user to an explanatory section as shown in Fig. 5b. The user can learn more about any particular type of defect and the corresponding repair solution, with the aid of photographic images, by selecting the appropriate button in Fig. 5b. Inspection of a member is completed after the user has selected the appropriate checkbox(s) and pressed 'replace' or 'insert' database function key in Fig. 5a.

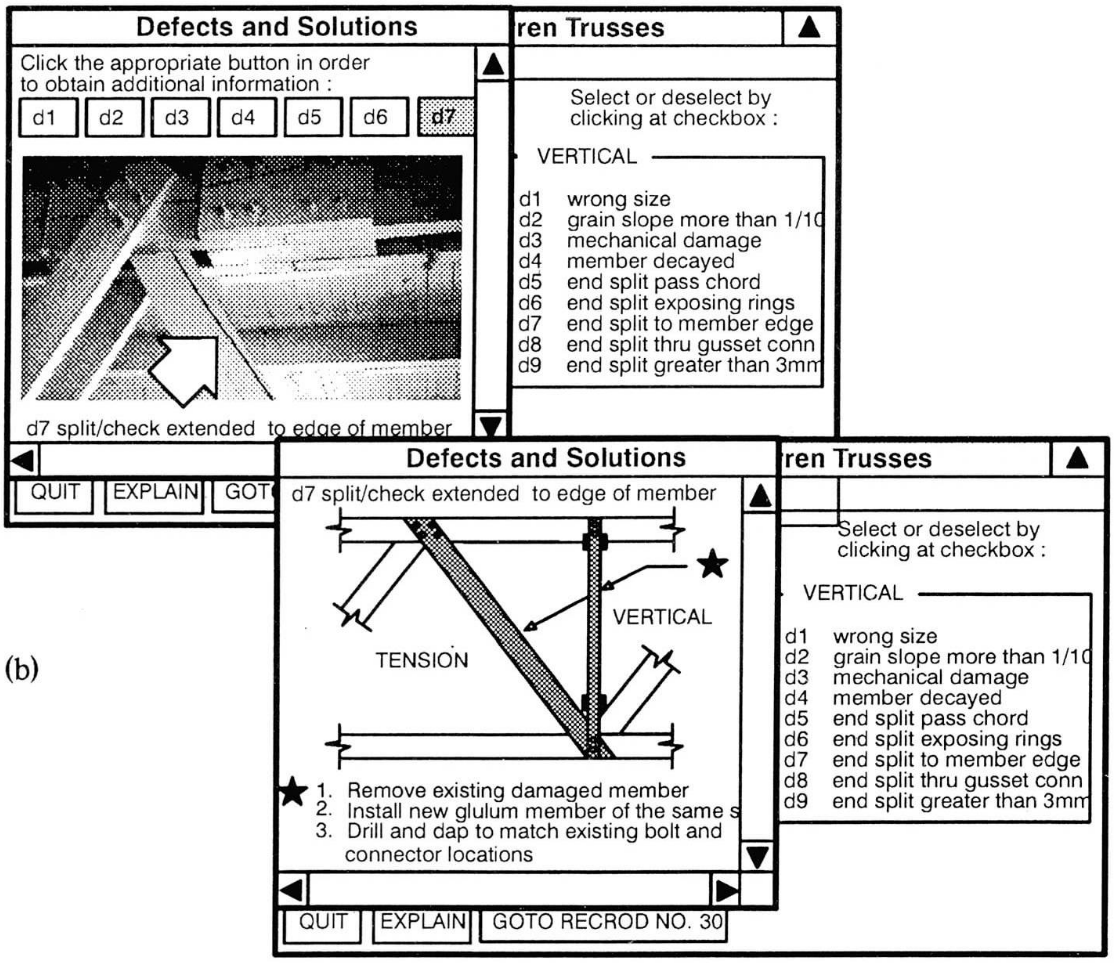
5. AN OBJECT-ORIENTED SYSTEM FOR DATA MANAGEMENT

5.1 System Description

To maintain a huge network of aging buildings, historic data as well as data to be collected from future inspection projects need to be stored and managed properly and effectively. A system is being developed for database management. The system allows direct communication



(a)



(b)

Fig. 5 Typical screen displays of inspection system with external programs and databases, using a management system that integrates and controls the interaction between the knowledge base and the databases. Direct database access enables the system to read and write to files directly from within the knowledge base.

In an object-oriented database management system, data and procedures are coupled. The system views these database entities as objects, which are referenced and manipulated with standard Production Rule Language grammar. Each object combines attributes of procedures and data. The attributes of a class and their attribute types correspond to fields and field types in the external database. Instance of an attribute represents the records in a database.

5.2 Example

Fig. 6a and 6b represent the typical screen images during a consultation session with the database management system. Fig. 6a is the selection display which controls the display and search functions of the system. Depending on the selection option chosen by the user, the system can display data for all records one at time, search and display any record as specified by the user, search and display records related to a particular distress problem, or conduct a relational search. User can specify up to three criteria for the relational search (Fig. 6a). The search shown in Fig. 6b was based on member name and date of the inspection.

(a)

(b)

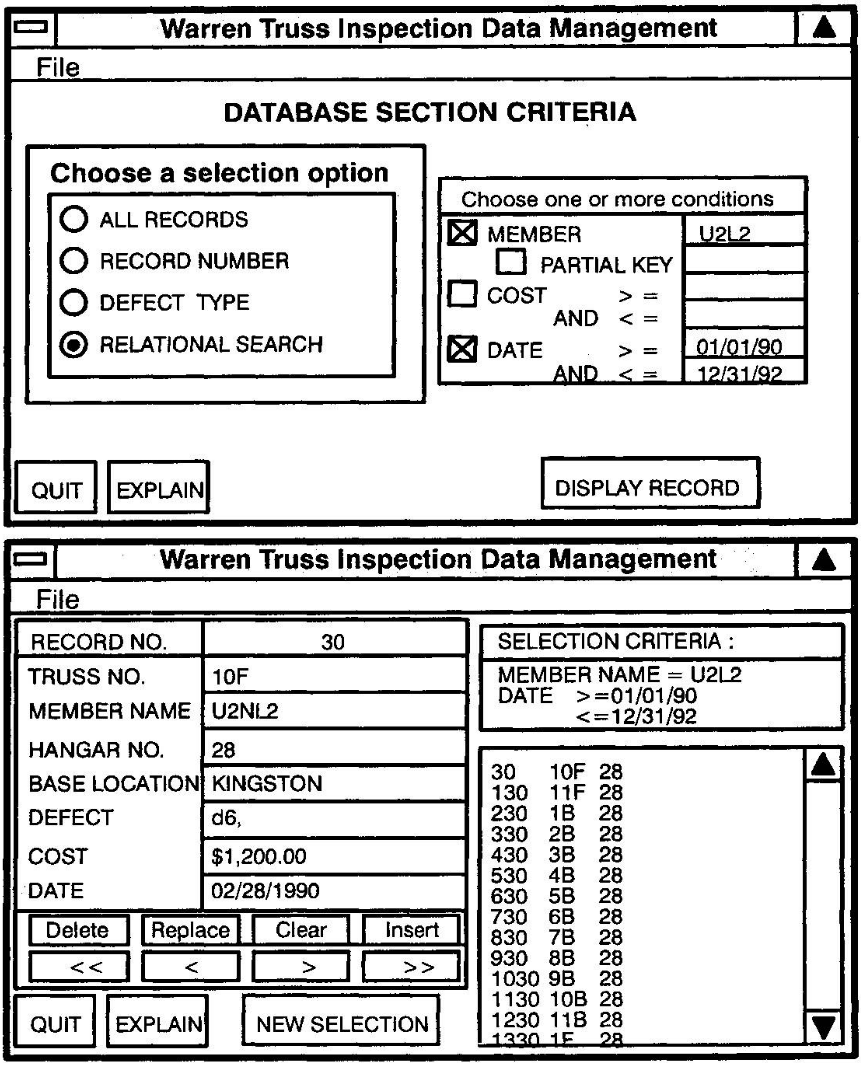


Fig. 6 Typical screen displays for data management system

6. CONCLUSIONS

Expert systems are productivity tools. The availability of sophisticated expert-systems development software for personal computer systems has made the design and development of very complex expert systems possible for engineers who are not computer professionals. Fully developed knowledge-based expert systems can perform certain tasks, such as decision support, design aids and training more effectively and consistently than is possible with current tools and engineering aids.

The development of an object-oriented expert system for the inspection of timber Warren trusses is described. The proposed system integrates the concepts of expert systems, object-oriented programming, relational database and graphics. The system is being developed on and for personal computers. The portable system can be used in the field by inspectors and in the office by management personnel.

7. ACKNOWLEDGES

The financial assistance of the Department of National Defence of Canada is gratefully acknowledged.

8. REFERENCES

1. DEPARTMENT OF NATIONAL DEFENCE OF CANADA, 34 m Warren Type Wood Trusses and Columns Maintenance. Construction Engineering Technical Order, C-98-006/TP-002, National Defence Headquarters, Ottawa, Ontario, 1967 and 1988.

2. FOO H.C. and AKHRAS G., Inspection of DND Warren Truss Buildings Using KBES in a Windowing Environment. Proceedings, Fourth Symposium/Workshop on Applications of Expert Systems in DND, Kingston, Ontario, April 1992.

3. AKHRAS G. and FOO H.C., Timber Truss Inspection Using a Graphical Object-Oriented Expert System. submitted for publication in the Journal of Microcomputers in Civil Engineering.

4. COX B., Object-Oriented Programming : An Evolutionary Approach. Addison-Wesley Publishing Co., Menlo Park, California, 1988.

5. PASCOE G.A., Elements of Object-Oriented Programming. Byte, McGraw Hill, Inc., New York, 1986.

6. TESLER L., Programming Experiences. Byte, McGraw Hill, Inc., New York, 1986.

7. GOLDBERG A. and ROBSON D., Smalltalk-80 : The Language and Its Implementation. Addison-Wesley Publishing Co., Menlo Park, California, 1985.

8. INFORMATION BUILDERS INC., Level5 Object : User's Guide. New York.