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Autor: Smith, Ian F.C.

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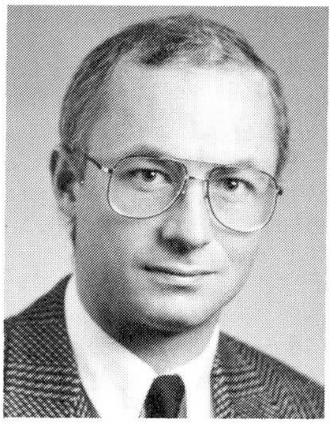
Crack Control: Decision Making Aided by Knowledge Processing Technology

Aide à la décision grâce aux systèmes de traitement de la connaissance

Entscheidungsfindung unterstützt durch Datenverarbeitungssysteme

Ian F.C. SMITH
Research Associate
Swiss Fed. Inst. of Tech.
Lausanne, Switzerland



Dr. Smith received engineering degrees from Cambridge University, U.K. and the University of Waterloo, Canada. Over the past fifteen years, he has worked in research, design and construction in several countries. Presently at ICOM, he is performing research into engineering applications of knowledge processing technology and fatigue of metal structures.

SUMMARY

Issues associated with remaining fatigue life are well suited to applications of knowledge processing technology since critical information can be badly organized and poorly distributed. This paper describes a small system called CRACK CONTROL developed in order to help engineers make decisions when a crack is discovered in a steel structure. Incomplete and inexact information is accommodated through approximately sixty questions asked by the system during a typical session. The system helps determine the causes of cracking and then provides recommendations for action – including proposals for subsequent management of the structure. This system could serve as one module in a set of decision aids which are made available to engineers and maintenance staff.

RÉSUMÉ

Les conclusions relatives à la durée de vie restante s'appliquent bien aux techniques de traitement de la connaissance, parce que l'information nécessaire est mal structurée et encore peu répartie. Cet article traite d'un système appelé CRACK CONTROL développé dans le but d'aider les ingénieurs à prendre des décisions quand une fissure est découverte dans une structure en acier. L'information, incomplète et inexacte, est acceptée par une soixantaine de questions qui sont posées par le système pendant une session. Le système aide à déterminer les causes de la fissuration et propose des recommandations – y compris des propositions quant à la gestion de l'ouvrage. Ce système pourrait servir de module dans un ensemble d'aides à la décision qui seraient disponibles aux ingénieurs et aux responsables de la maintenance.

ZUSAMMENFASSUNG

Da Informationen zu Fragen der Restlebensdauer bestehender Bauwerke nur schwer erhältlich sind, ist die Anwendung von Datenverarbeitungssystemen für diesen Problemkreis besonders geeignet. Der vorliegende Artikel beschreibt ein System namens CRACK CONTROL, welches Ingenieuren helfen soll Entscheidungen zu treffen, falls in einer Stahlkonstruktion Risse entdeckt werden. Unvollständige und ungenaue Informationen werden mit Hilfe von etwa sechzig Fragen, die durch das System an den Benützer gerichtet werden, ergänzt. Das System hilft die Ursachen zu bestimmen, die zu einem Riss geführt haben, und liefert Empfehlungen für Gegenmassnahmen und Vorschläge für den Unterhalt der Konstruktion. Es ist ein Hilfsmittel, das Ingenieuren und Unterhaltspersonal zur Entscheidungsfindung dient.

1. INTRODUCTION

Determination of remaining fatigue life is complex. Although more work is needed to obtain new information and to develop better models, an additional effort - taking advantage of existing knowledge - is justified. Currently, much relevant information is concentrated among a small group of experts. For the most part, written knowledge is available through scattered comments within documents devoted primarily to other themes. As the average age of structures increases, the need for understandable, organized and widely distributed knowledge grows.

Applications of knowledge-processing (expert system) technology are developed in order to improve representation and distribution of knowledge. Operating systems, especially those assisting diagnostic tasks, in other fields have been successful. For example, a system in the car manufacturing industry is credited with saving one company over ten million dollars each year [1].

Civil engineers have been slow to accept such new possibilities. This is understandable since civil engineering is a fragmented and necessarily conservative field where new techniques are not embraced blindly. Also, practical applications have necessitated processing speeds and memory requirements that were possible only using machines and software which are not compatible with the activities of civil engineers.

Recently, this situation has changed. Improvements in personal-computer capacity and less expensive software has created a situation where sufficient speed and memory is available in small offices and on site at reasonable cost. As a result, civil-engineering interest in this technology is growing, for example see [2-5]. Tasks associated with remaining fatigue life of steel structures stand to benefit from such trends, especially since such activities involve problem solving procedures akin to diagnosis.

This paper examines the potential of knowledge systems for remaining fatigue life and presents a system called CRACK CONTROL - created in order to help engineers make decisions when a crack is discovered in a steel structure. Representation, implementation and verification aspects are discussed. Finally, the development of a large system for activities related to managing structures in service is explored.

2. KNOWLEDGE SYSTEMS FOR REMAINING FATIGUE LIFE

It is of interest to examine the difference between knowledge development and knowledge management within the context of remaining fatigue life. Knowledge development includes activities such as analysis, modelling, parametric studies, laboratory testing and site measurements. Knowledge development generates new facts and identifies causal relationships. On the other hand, knowledge management concentrates on improving the way existing knowledge is used. Elements of knowledge management include acquisition, organization or representation, knowledge distribution, default knowledge and revision. A summary of these elements is given in Table 1.

TABLE 1 Difference between knowledge development and knowledge management

IMPORTANT ELEMENTS OF

KNOWLEDGE DEVELOPMENT	KNOWLEDGE MANAGEMENT
Analysis	Acquisition
Modelling	Organization
Parametric studies	Distribution
Laboratory testing	Defaults
Site measurements	Revision
...	...

For example, load modelling, dynamic analyses, corrosion studies, crack growth measurements, fracture mechanics analyses, fracture and fatigue testing, field measurements, numerical simulation, development of crack detection technology, and life improvement studies are knowledge-development activities. Assimilation of new research, code writing, record keeping, communication, co-ordination, planning, knowledge structuring, updating and learning are concerned with knowledge management.

In a recent study of over 600 structural failures in the United States from 1975 to 1986, a large majority of cases could be attributed to poor knowledge management [6]. Cases of lack of fundamental knowledge, classified as "unknown situations", made up only one third of all failures. This is probably an over-estimate of failures caused by a lack of fundamental knowledge since the term "unknown situations" was not defined and consequently, it is conceivable that other factors such as inadequate records had some influence. Similar studies have reached the same conclusions, for example [7] [8].

Therefore, improvements in knowledge management may have a greater impact on structural engineering than additional knowledge development. In addition, explicit organization of knowledge may identify previously un-noticed shortcomings in existing knowledge and thus initiate useful research [9]. Another advantage of explicit knowledge representation is that it is more resistant to what is termed "knowledge erosion" due to transfers, retirements and resignations of personnel.

Many opportunities for creating knowledge-processing systems exist, and work in progress, for example [2][10] represents a small proportion of possible systems. For any development effort, a prerequisite for good solutions is a complete definition of the problem. Often, the original definition is inaccurate because relevant knowledge and user needs were not defined accurately. Therefore, an attempt should be made to develop a small prototype as soon as possible in order to begin testing the system at an early stage. An example of such a system is presented next.

3. A CRACK IN A STEEL STRUCTURE

A system called CRACK CONTROL was developed to help engineers decide what to do if a crack is discovered in a steel structure. Intuitive repair solutions such as filling the crack with weld metal may not be effective. Good decisions require a combination of scientific knowledge and experience gained through examining cracks in structures. Generally, if a crack is found in a steel structure, more careful inspection will reveal additional cracks in similar elements. If no action is taken to eliminate the cause of cracking, more cracks usually appear at other locations. These heuristics have an influence upon the knowledge structure described below.

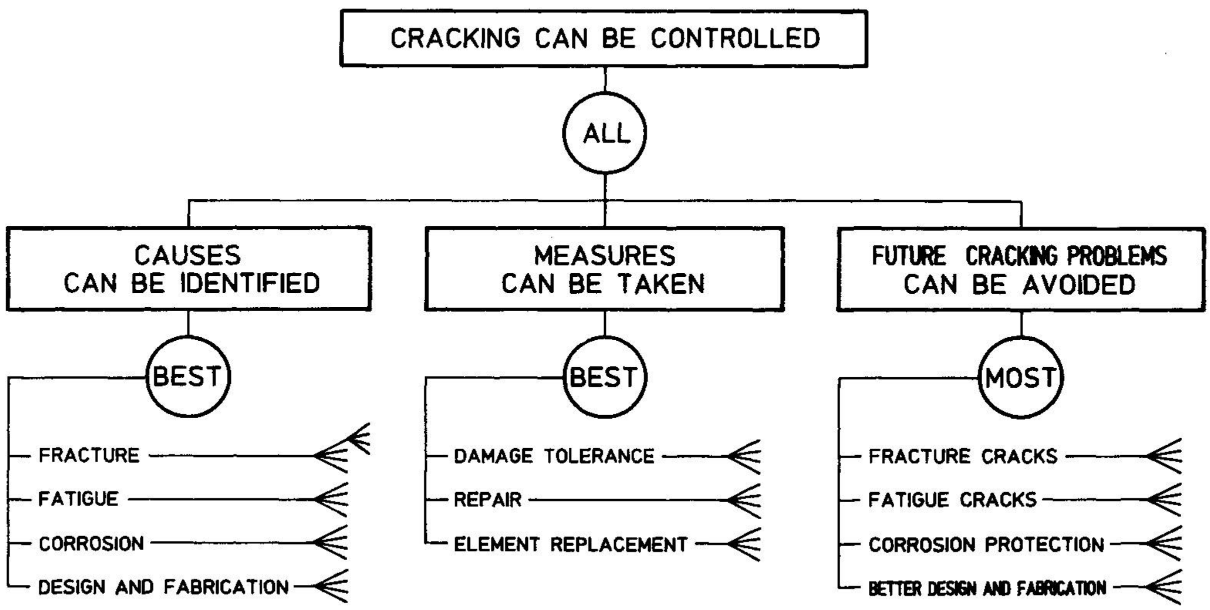


FIGURE 1 Partial inference net of CRACK CONTROL

The knowledge necessary to solve this problem is split into three parts, as shown in Figure 1. The first part concentrates on parameters which cause cracks in steel structures and thus, it contains the majority of the diagnostic knowledge in the system. This knowledge is split into categories which reflect the origins of cracking. Cracking may be due to fracture, fatigue, corrosion or design and fabrication practices, or most often, a combination of these factors.

The second part of the knowledge focuses on the most appropriate action, given a cracked element. Measures to be taken are subdivided into damage tolerance, repair and element replacement. Damage tolerance involves no immediate repair but an increased inspection effort. This solution is only explored under certain conditions since it is not appropriate if, for example, further crack growth could cause catastrophic collapse. Repair measures are dependent upon the causes determined in the first part. Element replacement is a valid measure when damage tolerance and repair are not practicable.

The third part of the knowledge concentrates on identifying a maintenance strategy for the rest of the structure. Once cracking has been discovered in a steel structure, the maintenance effort needs to be modified since more cracking is likely. While these considerations do not depend greatly upon the measures chosen for the cracked element, they are closely linked to the causes determined in the first part. Also, several general precautions are needed regardless of the cause of cracking.

This knowledge was implemented rapidly into a small system using a development tool specifically designed for diagnostic applications - THE DECIDING FACTOR (TDF) [11]. This tool was developed using experience gained during the PROSPECTOR project [12] and it has already been employed for diagnostic applications in civil engineering, e.g. [13].

Rather than require direct input of production rules, TDF processes knowledge organized in inference nets, see, for example, Figure 1. The user expresses opinions related to ideas low down on the net. These opinions are transferred into a belief value and multiplied by a factor to contribute to the hypothesis represented as the parent of a set of ideas. In turn, sub-hypotheses contribute to hypotheses further up on the net. Belief values are combined using special logical relationships provided by TDF. In Figure 1, ALL, BEST and MOST are three of eight possible relationships. ALL and MOST pass weighted averages of belief values, whereas BEST passes the highest belief value. Thus, BEST is analogous to OR logic. The system, CRACK CONTROL, employs six relationships in all.

One of the strong points of TDF is the user interface, see Figure 2. Typically, a question screen is composed of an introductory explanation, a question, an answer box and a scale of possible answers. The user manipulates the cursor in order to adjust his answer. A definite reply of yes or no is not needed.

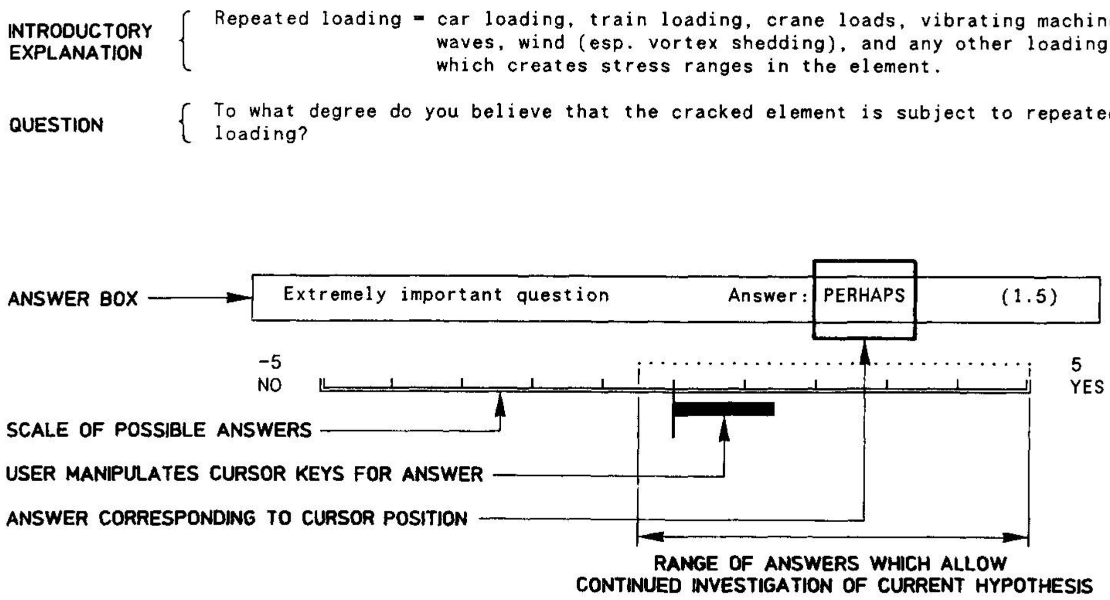


FIGURE 2 CRACK CONTROL User interface

Intermediate answers such as MAYBE SO and THINK NOT are possible. The middle of the scale is the reply, DON'T KNOW. This feature is very useful for applications to structures in service since information is rarely complete and never certain. This interface has been well accepted by users during tests.

Questioning proceeds from left to right in the inference net (Figure 1). It is possible to fix a range of answers, thereby allowing continued investigation of the ideas which contribute to the current hypothesis. If the user replies outside this range, questioning relating to the current hypothesis is terminated, and the system goes on to the next part of the net. For example if damage tolerance was the current hypothesis and the user had any doubt whether further cracking would lead to catastrophic failure, the system would not pursue this possibility further. Therefore, questions which would have followed, relating to the safety and economy of a damage tolerance philosophy, would not be asked, and repair would be investigated.

A final step in the system involves a review of the recommendations provided for the particular case. Note that heuristic information is used only to identify the most appropriate recommendations. Once these are identified, the user is asked to what extent he believes that the recommendations can be carried out. This belief determines which recommendations are reviewed and ultimately used by the system to evaluate the hypothesis that cracking can be controlled. Note that this system performs no calculations; the focus is placed entirely on prior qualitative reasoning.

Due to the ease of development, a working prototype was ready for testing two weeks after development began. Many changes were introduced after initial tests. Indeed, it was discovered that the problem was not completely defined from the start. Some measures for dealing with cracked structures were overlooked. Users employ a different language than experts and sometimes prefer that questions are raised in a different order. A small system developed rapidly using a simple tool created a situation where these differences were identified as quickly as possible.

4. LARGE SYSTEMS FOR MANAGEMENT OF STRUCTURES IN SERVICE

Activities associated with the management of structures in service are shown in Figure 3. Over their lifetimes, structures are subjected to monitoring, evaluation, maintenance and perhaps, modification. All of these activities could benefit from better organized and more widely distributed knowledge.

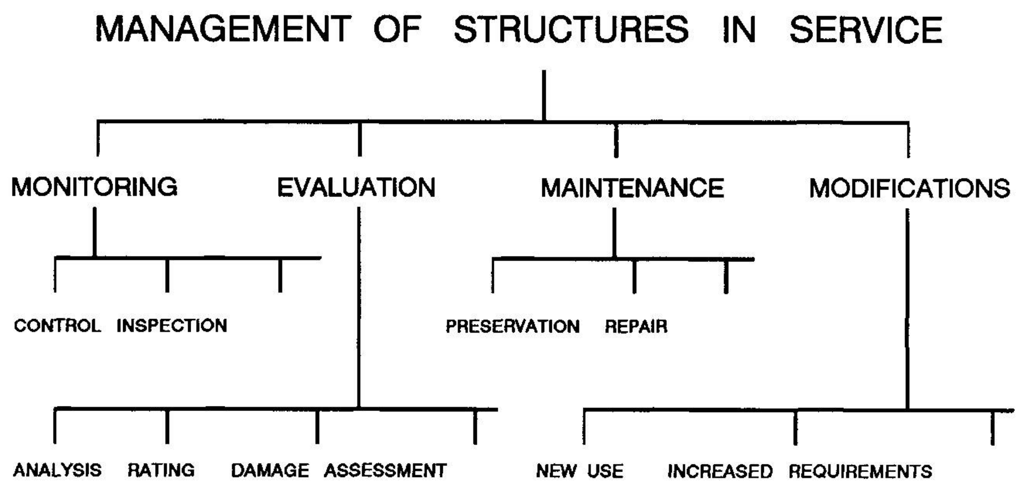


FIGURE 3 Activities associated with management of structures in service

Each activity in Figure 3 requires diagnostic or classification procedures to be most effective. These procedures are important for identifying good solutions and areas where more information would be most helpful. Nevertheless, a distinct focus is required for each activity since the user wishes to proceed differently for each case. Therefore, each activity has a unique set of rules which make up and control the methods employed during solution formulation. However, much of the information used by these methods is similar. Also, solutions implemented during different activities can affect each other. Common information requirements and possible interaction can be well accommodated by an integrated system. A proposal for such a system is presented next.

Small systems developed rapidly for testing help to ensure that effort is not wasted solving the wrong problem. Knowledge is verified at an early stage and the requirements of the user become well defined. However, as the size of the problem grows, the number of assertions increases rapidly. Interaction between these assertions becomes difficult to manage and verification of all possible solutions is increasingly arduous. Well organized knowledge becomes essential.

Models and more abstract reasoning provide effective ways to organize knowledge. Generally, two types of models could be used to simulate structures in service. The first type is a mathematical description of the behaviour of the structure. Examples of models of this type include structural-analysis algorithms, fracture-mechanics simulations and fatigue-damage-accumulation techniques.

The second type is a representation where the design and function of the structure is described. Figure 4 gives an outline of such a model of a structure. In this figure, actions, such as gravity loads and wind, act on the structure. The structure is described in terms of the material employed, elements and their connections to each other, details at connections and attachments, built-in stresses, etc. The structure acts on the foundations, which for the purposes of this outline, include surrounding soil and geological properties. External factors, such as salt-water exposure, atmospheric pollution and changing ground-water levels also act on the structure and foundations. Also, changes in the behaviour of the foundations over time may in turn affect the behaviour of the structure.

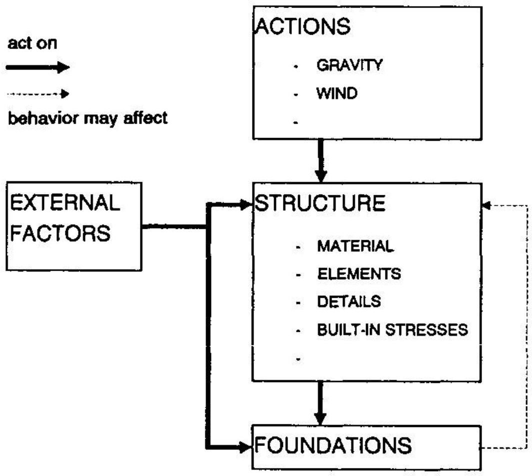


FIGURE 4 An outline of a functional model of a structure

Recent work in artificial intelligence has examined the advantages of domain-independent reasoning for diagnostic activities, e.g. [14]. Using models such as the one outlined in Figure 4, domain-independent theories provide methods for diagnosis from first principles. Given a state which is observed to be outside the limits of expected behaviour, models can help identify the origin of faults. They provide a means of representing knowledge for large quantities of information and complicated relationships. Therefore, models are important to the future of large diagnostic systems [15].

A further advantage of models is that they are useful for a range of activities. For example, the model in Figure 4 could be employed for many of the activities shown in Figure 3. On the other hand, systems using only heuristic pattern matching are typically constructed to do a specific task.

However, first-principle models [14] are not useful for many types of practical problems. An exact model of the system is required, and uncertain information cannot be treated. As the number of possible faults increases, computation time rises exponentially. If multiple faults are considered, models are especially sensitive to problem size. Therefore, first-principle diagnostic models are most useful for medium sized "closed-world" problems such as small electrical circuits.

Problems associated with structures in service are very different from small electrical circuits. Important information may have a high degree of uncertainty. Relationships between objects may be poorly defined. A structure may have thousands of elements and details, and tens of load cases. In addition, critical measurements may be very difficult to carry out and external factors may include social and political considerations. These factors mean that structures in service have "open-world" characteristics.

Research into artificial intelligence has developed new techniques which are very useful for representing activities associated with structures in service. For example, specialized strategies used with inexact models may help reduce the difficulties associated with existing structures. Rather than attempting to construct complete models, inexact models contain only knowledge relevant to a group of activities [16]. Other developments in non-monotonic reasoning and machine learning have created many opportunities for applications involving ill-defined problems such as those typical of structures in service. These techniques are often implemented within a system which employs various reasoning methods.

A hybrid approach for activities associated with structures in service is proposed. The user would start the system by providing information which identifies modules that are appropriate to the problem. The majority of these modules would be activity-dependent. However, some modules, such as those used to estimate behaviour, would be used for several activities. For example, modules such as CRACK CONTROL would be chosen from a library of available small systems. At this point, the system would carry out reasoning using heuristic knowledge which is independent of the structure in question.

The findings of the system would then be assessed by the user. If an acceptable solution was identified, the system would not invoke methods of more abstract reasoning. This step is comparable to traditional engineering methods since engineers typically employ more sophisticated methods when acceptable solutions are unavailable through simpler approaches. Also, if models of the structure do not exist, this step enables the advantages of model creation to be assessed. The complexity of some structures in service could require a substantial investment in order to produce useful models.

If an acceptable solution is not identified, the system would envoke reasoning using structure-dependent models and more abstract heuristics. For example, if a crack is discovered in a steel structure, reasoning could help identify candidate causes of the cracking by backtracking and examining all factors which affect the element. Optimal locations for additional measurements could be identified and when new information is received, the candidate list would be updated. Most likely causes, learned from previous experience with this structure and others like it, could be placed in default slots; reasoning with such information would proceed until evidence disqualified the assumption. Similar procedures could be employed for identifying other areas at risk in the structure and for evaluation of repairs. As stated already, new research in artificial intelligence has created conditions where these capabilities are applicable to activities associated with structures in service.

The models used would be independent of activities such as those in Figure 3. In this way, information would be shared as required by the particular task. However, many heuristics would be activity dependent, especially those which control how the model is examined. Also, information obtained in the structure-independent reasoning stage would be used for pruning search.

CONCLUSIONS

1. Improvements in knowledge management through applications of knowledge-processing technology could have an important impact on decisions relating to remaining fatigue life. New and current work should improve capabilities to manage knowledge, thereby reducing costly repairs and unnecessary replacement of steel structures.

2. Since the factors which influence existing structures are complex, it is essential that knowledge-base development begins with a rapidly developed prototype for testing with the expert and the user.

3. Models help organize the knowledge necessary for large diagnostic systems. However, for problems encountered by structures in service, a purely model-based system, controlled by domain-independent heuristics, is not appropriate.

4. A hybrid system which combines heuristic reasoning with model-based reasoning is a feasible and effective approach for structures in service.

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