Prediction of Structural Damage by Using Expert Systems Technology

Prèdiction des dommages structuraux par systèmes experts

Schadenprognose für Stahlbetonbauten mittels Expertensystemen

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SUMMARY
This work deals with the development of a data base for the damage level evaluation of reinforced concrete structures affected by severe fire. This data base was coupled with a bayesian engined expert system, called EECC (Engineering Evaluation of Critical Conditions). Several hypotheses and evidences were considered and codified into the data base. Some illustrative examples are presented and discussed.

RÉSUMÉ
La présente étude porte sur le développement d'une base de données destinée à évaluer les dommages subis par les constructions en béton armé, à la suite d'incendies de grande envergure. Cette base de données a été reliée à un système expert appelé EECC (Engineering evaluation of critical conditions). Elle comporte un grand nombre d'hypothèses et de facteurs d'influence sélectionnés à cet effet. Les auteurs présentent en outre quelques exemples d'application.

ZUSAMMENFASSUNG
Die vorliegende Arbeit befasst sich mit der Entwicklung einer Datenbasis zur qualitativen Schätzung von Schäden in Stahlbetonbauten nach Bränden. Die Datenbasis wurde mit Expertensystem EECC (Engineering Evaluation of Critical Conditions) verbunden. Verschiedene Hypothesen, Grundannahmen und Einflussfaktoren wurden für die Datenbasis ausgewählt und eingefügt. Einige Beispiele werden diskutiert.

1. INTRODUCTION

Figure 1 illustrates the typical architecture of an expert system. As it can be seen, the kernel of the system is made up by the knowlegde base and the inference engine.

The knowledge base essentially collects the "knowledge" of the computer, in terms of production rules, frame structures, rets, etc. [1,2,4]. Of course, this knowledge can be codified with probabilities associated to the production rules, which is the most often case in engineering in view of the probabilistic nature of the engineering processes.

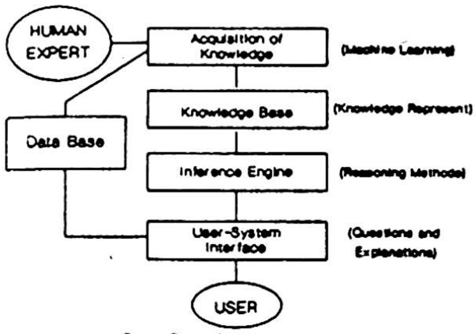

Figure 1. Typical Expert System Architecture

The inference engine peforms the "reasoning" of the system, by combining the production rules to produce "intelligent" responses. Expert systems technology has experimented an exponential development in the last few years. In the case of engineering, a great number of expert systems has been developed to assist the specialists in the realization of non-trivial works, thus giving an improvement of the human performance. A large list of expert systems in many engineering fields are briefly described in refs.[2,3].

This work deals with the development of knowledge bases for the damage level evaluation of reinforced concrete structures affected by severe fire, as well as the risk prediction in slope unstability problems. These knowledge bases were coupled with an expert system (Engineering Evaluation of Critical Conditions EECC). Also, three modules to help the user were developed: a) a justification module, which is able to explain (at the user request) the reasoning path followed by the bayesian inference engine, b) an on-line help module, which provides the user with a more detailed explanation of technical terms appearing in the computer questions and c) a suggested reparations module, which gives the inmediate actions that must be taken according to the damage level detected.

2. THE BAYESIAN APPROACH

The Bayes theorem has a singular importance when dealing with phenomema involving probabilistic information. Some examples are engineering design, damage assessment, prediction of attributes, etc.. In such cases, information is available from several sources, namely: experimental tests, engineer's experience, visual inspection, etc.. In what follows, we will briefly review the basic ideas of the Bayes theorem. Let U be the universe comprising a set of a mutually exclusive events Hi and Ej another event which also belongs to U. The conditional probability for the presence of event Ej, assumed that event Hi is present, is:

$$P(Hi:Ej) = P(Hi\&Ej)/P(Ej) \qquad (1)$$

where

P(Hi&Ej) = probability for the ocurrence of both events simultaneously

From (1) it can be obtained

$$P(Hi:Ej) = P(Ej:Hi) * P(Hi) \quad (2)$$

Thus, Bayes theorem could be written as follows:

$$P(Hi:Ej) = P(Ej:Hi) * P(Hi)/P(Ej) \quad (3)$$

In the present analysis, Hi should be interpreted as an hypothesis, while Ej must be viewed as a piece of evidence:

P(Hi) = probability "a priori" for the presence of hypothesis Hi

P(Hi:Ej)= probability "a posteriori" for the presence of Hi, updated with the information of evidence Ej

P(Ej:Hi)= conditional probability for the presence of Ej, assumed the presence of hypothesis Hi.

3. BRIEF DESCRIPTION OF THE EXPERT SYSTEM

The expert system developed during this research, named Engineering Evaluation in Critical Conditions (EECC Ver 2.1), is a computational system written in Pascal. It uses the Bayes theorem for performing the inference process, related to both prediction and diagnosis of real-world environments.
The inference engine was defined separately from the knowledge base. It is able to process "a priori" information, which is supplied mainly by human experts as well as "a posteriori" information, which is provided by the expert system user.
In this work, the "a priori" information was clasiffied, for the sake of clarity, into three main items: beams, columns and slabs. This strategy allowed the treatment of different structural components subjected to the same level of fire severity. The wide spectrum of practical damage levels in structures subjected to fire was discretized into four main categories, as follows:

* Slightly affected
* Moderately affected
* Strongly damaged
* Severely damaged

On the other hand, three modules for helping the user in the interpretation of the program performance, were developed and coupled with the system. The justification module explains the user the path followed by the system in the actual inference process. This justification process is based upon a permanent evaluation of the effect caused by the user answers on the probability values of the hypotheses currently under analysis.
Two sets of linguistic variables were created, in order to facilitate the user-computer communication. The former assigns the numerical user-answer a linguistic variable, which is used latter in the justification report. The second set was coupled to a mathematical function which evaluates the shift in the probability values caused by the user-answer.

The on-line help module allows the user to get a more detailed information regarding the current question prompted by the computer, since the questions in the knowledge base were formulated in a very synthetic manner and by using technical language.
The corrective module herein implemented was designed with the aim to provide the user the immediate required actions that must be undertaken according to the diagnostic given by the system. It must be emphasized that the corrective module is not intended to replace neither the human expert appreciation nor the need of experimental tests; it was just conceived to give some basic actions at a first glance.

4. ILLUSTRATIVE EXAMPLE

The knowledge base developed here was extensively tested and modified taken into acount the suggestions made by the human experts. Also, some critical situations were considered, giving satisfactory results.
The present example pressuposes the existence of a reinforced concrete beam affected by a severe and long-term fire. As a consequence, the beam shows strong symptons of structural damage.
The following text reproduces the dialog user-computer, when the above described example was analysed.

Please, answer the questions according to the scale shown below:

AFFIRMATIVE		NEGATIVE
5: No doubts		-5: Categorical
4: Strongly		-4: Firmly
3: Reservedly		-3: Moderately
2: Weakely		-2: Feeble
1: Wondering		-1: Uncertain
	0: Total uncertainty	

EECC: Were there non-structural smelted steel observed ?
User: 5
EECC: Did the concrete remain undamaged ?
User: -5
EECC: Were there cracks observed ?
User: 5
EECC: Did the firemen extinguish the fire ?
User: 5

(As the dialog progress, the system incorporates more and more "a posteriori" information and, after some more questions, it reaches and announces its most likely conclusion.)

EECC: Was loss of frieze observed ?
User: 5
EECC: Did you observe loss of adherence between steel and concrete
User: 5

DIAGNOSIS: The beam is SEVERELY DAMAGED with a probability of 99%

In order to perform the assessment of system reliability, there were runned on the computer three typical examples, corresponding to the three structural components currently available in the program.
It is necessary to demostrate that the system do not "jump" around intermediate local situations and that the questions prompted by the computer are made in a logical manner, similar as a human expert may do. An ilogical sequence of the questions probably will reduce the confiability of the user in the system. The way selected to obtain the results shown in figures 2,3 and 4 is as follows: all the computer questions were answered with the same level of confidence. So, four probability values were obtained for each analysis. Figures 2,3 and 4 illustrates the responses of the system for a beam, an slab and a column, respectively. It must be remarked that the system always exhibited a conservative behavior in the presence of very uncertain situations. Also, the system showed an adequate convergence towards the limits expected in known situations. These encouraging facts estimulated the refinement and improvement of the knowledge bases. This process is currently being done, either by reformulation of the evidences and its associated hypotheses or by numerical modification of the conditional probability values. In both strategies, the presence of the human expert is an unavoidable requirement if one expect to get success.

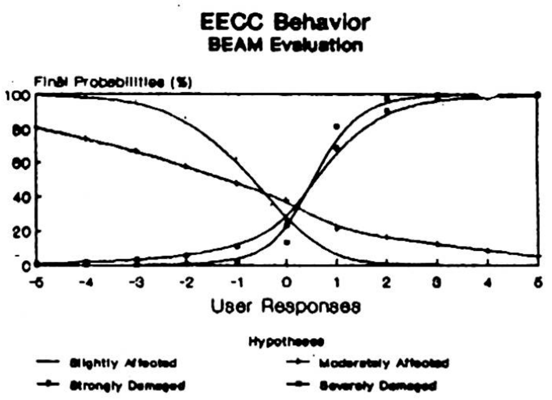

Figure 2.

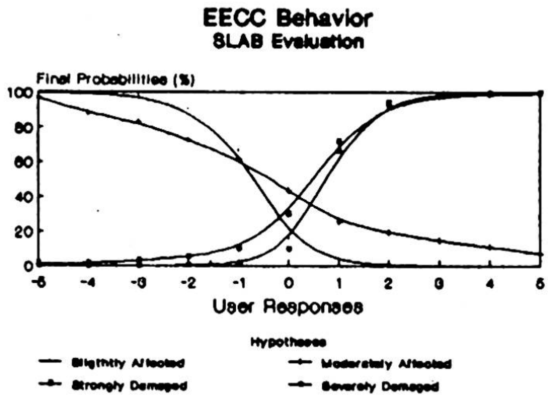

Figure 3.

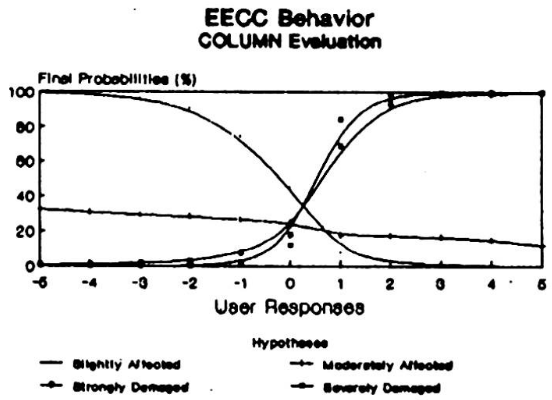

Figure 4.

5. CONCLUDING REMARKS

A knowlegde base for the evaluation of structural damage caused by severe fire on reinforced concrete structures has been developed. This knowledge base allows the user to know the damage level on either beams, columns or slabs of a certain concrete structure, that has been exposed to a long-term fire. As it is well-known, a wide variety of factors do affect a structural component when it is exposed to fire and, therefore, the evaluation of the current strength and confiability of such a component becomes an engineering subject of the most importance and not easy to be performed.

On the other hand, by reasons of space limitations, it was not possible to describe some preliminary results obtained when the expert system EECC was applied to the determination of security factors and risk assessment in soil slope unstability. However, it can be said that we have obtained a very encouraging results. Many practical soil engineering situations dealing with soil slopes were analysed with the computer, and it was observed that in more than 70% of the cases, the computer's prediction agreed with the human expert ones.
The complementary modules of EECC, i.e. justification, explanation and suggested reparations here developed, have substantially improved the behavior and performance of the expert system, as well as the user-computer interaction. Justification module explains the user the current reasoning path by using some sets of linguistic variables developed during this research. In this sense, the system is able to tinge his answers, so giving a really flexibility and a quite friendly behavior.
The on-line help module facilitate the user understanding of technical terms, which usually appears in specific engineering fields. Moreover, the powerful linkage of this two modules, help and justification, has shown that the system could be used as a tutorial for engineering students, provided that they have been appropiately trained in the subject.
The module of suggested reparations has also shown its usefulness. This module complements the diagnostic announced by the system, by providing some preliminar and unavoidable reparations, associated to the damage level, which must be performed on the structural component.
The cornerstone matter when dealing with expert systems development and implementation is usually the validation of the system. The EECC system, and its knowledge bases, have displayed an "smooth" behavior, without showing "jumping" around certain local points and clearly identifying limit situations. Moreover, the system produced diagnostics which agreed with human experts approximately over 80% of the cases treated herein.

7. REFERENCES

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