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Expert System for Repair of Concrete Structures

Système expert pour la reparation des structures en béton

Expertensystem zur Instandsetzung von Betonbauteilen

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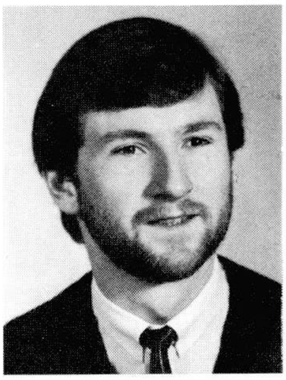

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SUMMARY
An expert system for the maintenance and repair of concrete structures based on an ES-Shell is discussed. The expert system is intended to help the civil engineer to investigate the condition of a building. The causes of damage will be revealed and analyzed in a dialogue between user and computer. After finding out the causes of deterioration different repair proposals are given.

RESUME
Un système expert, basé sur un Shell ES pour l'entretien et la réparation des structures en béton est présenté. Le système doit aider l'ingénieur qui juge l'état des bâtiments et des ouvrages d'art. Les causes des dommages sont analysées et expliquées pendant un dialogue entre l'utilisateur et l'ordinateur. Après la définition des causes des dommages, différentes possibilités de réparation sont proposées.

ZUSAMMENFASSUNG
Ein Expertensystem für die Unterhaltung und Instandsetzung von Betonbauteilen wird vorgestellt, das auf einer ES-Shell aufgebaut ist. Das Expertensystem soll Ingenieure bei der Beurteilung des Zustandes von Bauwerken unterstützen. Die Ursachen der Schäden werden in einem Dialog zwischen Benutzer und Computer analysiert und erläutert. Nachdem die Schadensursachen ermittelt sind, werden verschiedene Reparaturmöglichkeiten vorgeschlagen.

1. INTRODUCTION

The repair of damaged concrete structures has become more expensive in the last years. It was found that, in many cases, the engineers' training and experience was not enough to decide on the right repair works. There are exact scientific models for structural design but not for concrete repair. Here, the knowledge is dispersed in different papers, guide lines, regulations, and producers' instructions. There is a need to analyze the knowledge and experience and to prepare it for easier use on a higher level.

An expert system can save the knowledge of experienced engineers and combine the complex and heuristic relations. In our institute a prototype of an expert system is being developed, which is intended to support engineers in judging the damaged structures and to give repair proposals. The system includes the new regulations by the German Association for Concrete and Reinforced Concrete (Deutscher Ausschuß für Stahlbeton) entitled "Protection and Repair of Concrete Structures" [3] as far as they are released.

2. EXPERT SYSTEMS

2.1 Definition

Artificial intelligence is a field in computer research, where human performance is imitated with computers. To solve problems, intelligence is required. The human intelligence is devided into different abilities, such as understanding of the spoken language, parallel thinking, i.e. searching for a solution to a problem in different ways at the same time, or learning of new facts. One group, which is already well tested in practice, deals with knowledge-based expert systems.

Edward Feigenbaum, Stanford University, one of the prominent scientists in artificial intelligence, gave the following definition of expert systems:

> An intelligent computer program that uses knowledge and inference procedure to solve problems that are difficult enough to require significant human expertise for their solution [2].

2.2 Differences with conventional programming techniques

Conventional computer languages are e.g. FORTRAN, PASCAL, or BASIC. These languages are used for data processing of large data and for mathematical computations applying algorithms in always the same way. The main differences between conventional and symbolic programming languages are given in Table 1.

Table 1: Main differences between conventional and symbolic programs

Conventional Programs	**Symbolic Programs**
Algorithms	Heuristics
Numerical adresses in data base	Symbolic structured knowledge base
Orientation to numerical processing	Orientation to symbolical processing
Sequential, batch processing	Interactive processing
No explanations possible during program-run	Explanations during program-run easily

Most knowledge-based expert systems are written in symbolic or declarative languages, e.g. LISP or PROLOG. The systems are extensive interactive and the user can stop the consultation in order to ask why the system puts forward a particular question or how this resolution is done. Other advantages are the easy way of modifying the knowledge base, which is different from the inference mechanisms. Fig. 1 shows the tpyical setup of an expert system.

2.3 Applications of expert systems

Problems, which can be solved by experience on heuristics only, are suitable for use in expert systems. Some existing applications are listed in the following:

Diagnosis

The program must find the failure function of a system by analyzing the symptoms. These failure functions can be a disease of the human organism (e.g. MYCIN), mistakes in mechanical equipment, or damages to building structures (e.g. REPCON, discussed in chapter 4).

Planning

Planning tasks are e.g. to find the best hardware configuration for special applications, to make a financial decision, or to design buildings [1].

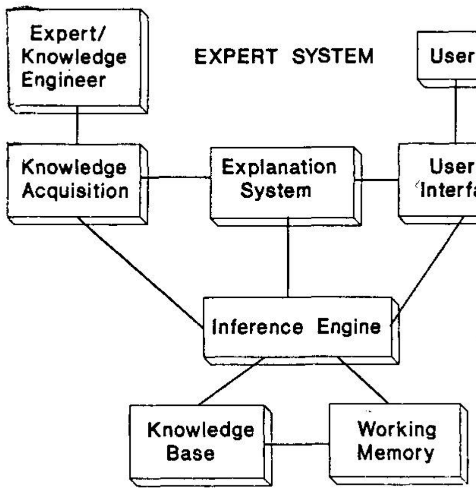

Figure 1: Typical setup of an expert system

Evaluation

Geological data must be evaluated for finding mineral resources (e.g. PROSPECTOR).

Supervision

Complex system functions must be supervised and the decisions must be made nearly in real time. Applications are used for intensive medical or mechanical equipment or ready-mixed concrete [7].

2.4 Expert-system shells

Expert-system shell means an expert system with an empty knowledge base. In our project, we use a shell named "Personal Consultant Plus" from Texas Instruments. The shell is written in the LISP-Dialect SCHEME. This shell was developed from EMYCIN (Essential MYCIN), i.e. the concepts of MYCIN, also certainty factors can be used. Frame-structure, Meta-Rules, and grafic facilities were added.

There are external accesses to MS-DOS, e.g. to start a program written in BASIC or PASCAL, or to send and read data from DOS-files. Hardware requirement is an IBM-compatible Personal Computer with a minimum of 640 kB RAM with grafic mode EGA.

3. CERTAINTY FACTORS

3.1 Purpose

A certainty factor (CF) is a numerical value that indicates a measure of confidence in the value of a parameter. Certainty factors in a knowledge base consider the real experience that facts and opinions are not always known with absolute certainty.

An expert system may encounter two kinds of uncertainty:

- The facts and relationships of the problem area encompass uncertainty. Frequently, the expert has to make statements like this: "If these conditions are met, this outcome occurs almost always. Once in a while, however, a different outcome may occur."
- The user may feel a degree of doubt in responding to a prompt. "I don't exactly know if there was a certain event in the life of the structure (for instance elevated temperatures), but I suppose there was."

3.2 Combining Certainty Factors

An example will show how the expert system deals with certainty factors. Supposing you find cracks in concrete structures and you have to find out the cause. The following two rules are part of the knowledge base:

Rule 1:
If: DAMAGE-MARK = CRACKS and
CRACK-TYPE = RANDOM-PATTERN and
ELEMENT = MASS-CONCRETE and
ENVIRONMENTAL-CONDITIONS-DURING-HYDRATION = LOW-TEMPERATURE

Then: CAUSE = LOSS-OF-HEAT-OF-HYDRATION CF 50

Rule 2:
If: START-OF-DAMAGE = FIRST-DAYS-AFTER-PLACEMENT and
CEMENT-TYPE is not LOW-HEAT-CEMENT

Then: CAUSE = LOSS-OF-HEAT-OF-HYDRATION CF 90

The consultation could run in this way. After having answered that you found RANDOM-PATTERN and the element was MASS-CONCRETE, the system prompts this:

"Describe the environmental conditions and indicate your degree of certainty". You may answer: "COLD with 70 % certainty." The conditions of the first rules IF-statement are met and the system combines the appropriate certainty factor, including the certainty factor you assigned in the rules THEN-statement.

CAUSE = LOSS-OF-HEAT-OF-HYDRATION CF 35 (70 per cent of 50)

The system considers other causes, because the conclusion is not true for 100 %. It will ask for the values of the parameters of rule two. Suppose you know that the damage started during the first days after placement. You don't exactly know the type of cement which was used, but you suppose that not a cement with low heat of hydration was used. You answer with a degree of certainty of 50 %. The expert system uses the following equations to combine the degrees of certainty.

$$CF(rule) = \frac{CF\ of\ IF - statement \cdot CF\ of\ the\ conclusion\ function + 50}{100} \quad (1)$$

$$CF = CF(previous) + \frac{CF\ (rule) \cdot (100 - CF(previous)) + 50}{100} \quad (2)$$

CF(previous) is the certainty factor with the parameters value before the expert system carries out the action of the THEN-statement of the next rule. Note that the last 50 in the numerator of the equations is included for rounding and only the integer part is used.

Example:
Using equation (1):

$$CF(Rule\ 1) = \frac{70 \cdot 50 + 50}{100} = 35,5 \Longrightarrow CF35$$

$$CF(Rule\ 2) = \frac{50 \cdot 90 + 50}{100} = 45,5 \Longrightarrow CF45$$

Using equation (2):

$$CF = 35 + \frac{45 \cdot (100 - 35) + 50}{100}$$

$$35 + 29 = 64 \Longrightarrow CF64$$

The cause of the cracks still is LOSS-OF-HEAT-OF-HYDRATION, but the additional evidence increased the certainty factor to 64.

4. "REPCON" AN EXPERT SYSTEM FOR CONCRETE REPAIR

First, the structure and the structural parts of a building have to be specified. Some important information may help to find the causes of damage, e.g. structures in sea water or near streets, should be tested for chloride content.

The causes of damage will be revealed and analyzed in a dialog between user and expert system. Different types of damages are presented in knowledge base rules, e.g. corrosion due to carbonization, chlorides, or chemical causes. The use of grafics with typical pictures of the damages supports the discussion and the analysis. Fig. 2 shows the structure of the expert system "REPCON".

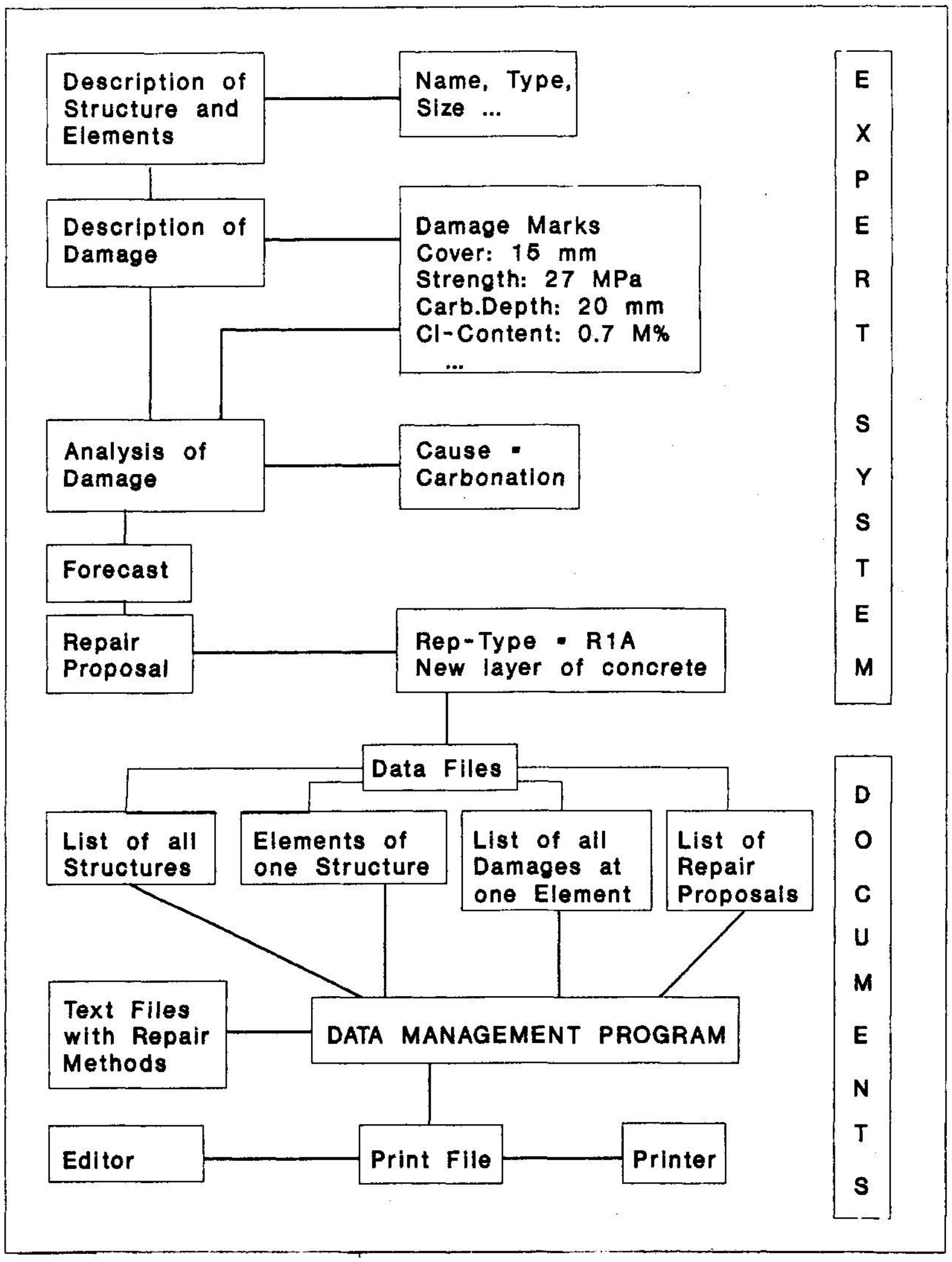

Figure 2: Structure of the expert system REPCON (with example)

All data necessary for the description of the structure and the repair will be saved in an extra data base for future consultations with respect to the same structure. After having found the causes for deterioration, different repair proposals will be given. The proposals comprise information about the repair method, repair materials, as well as quality of the repair work with respect to durability and esthetics and repairing expenses. At the end of the consultation, the user can receive a list of the input data and the conclusions drawn by the system.

5. CONCLUSIONS

An expert system for the maintenance and repair of concrete structures is being built on the basis of an ES-Shell. The expert system is intended to help the civil engineer to find out the condition of a building and to give repair proposals.

The prototype program REPCON shows that the use of an expert system is a possible way to save the knowledge, which is dispersed in numerous papers and in a few human experts. This kind of computer programs can help to make the right decision. They cannot and should not replace human experts.

References

[1] Baumgart, R.: CAD-Based Design Expert Systems for Reinforced Concrete Detailing. Darmstadt Concrete 2 (1987), pp. 9-18

[2] Barr, A., Feigenbaum, E.A.: The Handbook of Artificial Intelligence, Vol 2, Kaufman, Los Altos (California), 1982

[3] DAfStb, Schutz und Instandsetzung von Betonbauteilen (Protection and Repair of Concrete Structures), German Association for Concrete and Reinforced Concrete, Draft February 1989

[4] Texas Instruments, Personal Consultant Plus, Reference Guide, Austin (Texas), 1988

[5] Buchanan, B.G., Shortliffe, E.H.: Rule-Based Expert Systems: The MYCIN experiments of the Stanford Heuristic Programming Project. Adison-Wesley, Reading (Massachusetts), 1984

[6] Harmon, P., King, D.: Expertensysteme in der Praxis. Oldenbourg, München, 1986

[7] Seren, K.-J., Punakallio, E., Koskela, L.: An Expert System for choosing the type of ready-mix concrete. Nordisk betong 3-4, (1987), pp. 24