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Expert Systems for Quality Prediction in Structural Engineering

Systèmes experts pour la prédiction de la qualité dans le génie civil

Expertensysteme für die Qualitätsvorhersage im Bauingenieurwesen

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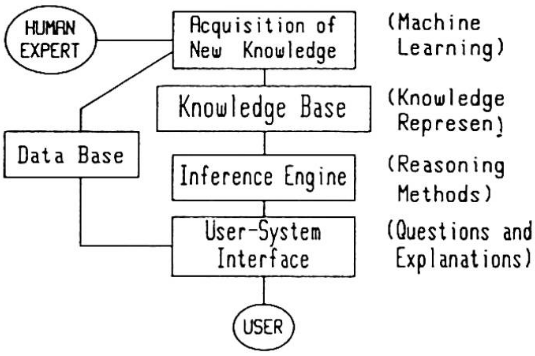
SUMMARY
This work deals with quality level prediction in concrete structures through the helpful assistance of an expert system which is able to apply reasoning to this field of structural engineering. Evidences, hypotheses and factors related to this human knowledge field have been codified into a Knowledge Base in terms of probabilities for the presence of either hypotheses or evidences and conditional presence of both. Human experts in structural engineering and safety of structures gave their invaluable knowledge and assistance, necessary when constructing the "computer knowledge body".

RÉSUMÉ
On étude la possibilité de prédire la qualité des bâtiments en béton à l'aide d'un système expert. Les évidences, les hypothèses et les facteurs en relation avec cette technique ont été introduites dans la base des connaissances avec une définition des probabilités correspondantes en relation avec les hypothèses et les évidences. L'ensemble des connaissances pratiques nécessaires pour prendre les décisions a été fournie par des ingénieurs experts dans les techniques du bâtiment.

ZUSAMMENFASSUNG
Diese Arbeit befasst sich über die Vorhersage des Qualitätsniveaus in Betonstrukturen, mit Hilfe eines Expertensystems für das Bauingenieurwesen. Die Grundannahmen und Einflussfaktoren in diesem Feld der Wissenschaften sind als Wahrscheinlichkeitrelationen in einer Datenbasis kodifiziert worden. Fachleute in der Strukturingenieurwissenschaft und in der Struktursicherheit haben ihre unschätzbaren Kenntnisse gegeben, die notwendig sind, um eine Computer-Datenbasis zu schaffen.

1. INTRODUCTION

In recent years, an ever-increasing effort has been devoted to the research, development and marketing of Expert Systems in a great number of specific fields - within human knowledge although only some of them have reached a truly "production" status. Likewise, Knowledge Engineering will have a really important impact in those areas of human activities where knowledge provides a powerful tool for solving relevant problems. Thus, it is possible to predict two beneficial effects [1]: an increase in knowledge based systems development for reproducing and applying human knowledge and, in second place, "... as an inevitable side effect, knowledge engineering will acelerate the development, clarification and expansion of human knowledge itself." Figure 1 illustrates a typical expert system with its basic modules. In some fields of human knowledge (medicine, law, mathematics) a considerable - number of expert systems have been developed [1,2,9,11]. In what follows, we briefly review some Expert Systems developed for structural engineering, in order to give an appraisal of the existing possibilities. SPERIL-II [6] evaluates the general safety and damageability of existing structures by analizing inspection data and instrumental records of the structural response as a consequence of earthquake loading. The system has a predicated logic rules KB and uses both forward and backward chaining combined with certainty factors. It was written in a dialect of Prolog. SACON [7], determines particular ways and strategies for analizing structural engineering problems. The system works coupled with program MARC (FEM code) using knowledge about stresses and displacements. It is a rule based system with backward chaining for the inference process. PROSPECTOR [8] is another expert system which helps geologists in their exploration and search for mineral deposits. The system works by using rule based knowledge and certainty factors, together with Bayesian inference. It was written in Interlisp and has reached the stage of production prototype.



This work is devoted to the generation of a Knowledge Base for quality Level prediction in concrete structures and its implementation on a Bayesian expert system, called "QL_CONST1" (Quality Level prediction in CONcrete STructures).

2. THE BAYESIAN APPROACH FOR PROBABILISTIC PHENOMENA

The well known Bayes' Theorem has singular importance in processes normally involving probabilistic knowledge, such as engineering design, damage assessment, etc. In these cases, information which must be included into the inference process is available from various sources: engineer's experience, visual inspection, experimental test, etc. We will briefly review the basic ideas and formulae inherent to Bayes' Theorem, as follows. Let U be the universe comprising a set of a mutually exclusive events Hi and Ej another event belonging to U. The conditional probability for the presence of event Ej assumed that event Hi has occurred is:

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

where

$P(Hi \,\&\, Ej)$ = probability for the occurrence of both events simultaneously

From (1) we can write

$$P(Hi : Ej) \,.\, P(Ej) = P(Ej : Hi) \,.\, P(Hi) \qquad (2)$$

Now, Bayes' theorem could be written as:

$$P(Hi : Ej) = P(Ej : Hi) \,.\, P(Hi)/P(Ej) \qquad (3)$$

In our case, Hi should be interpreted as a "Hypothesis", whereas Ej is an "evidence". Thus,

$P(Hi)$ = probability "a priori" for the occurrence of hypothesis Hi.

$P(Hi : Ej)$ = probability "a posteriori" for the occurrence of Hi, updated by - knowing the evidence Ej.

$P(Ej : Hi)$ = conditional probability for the presence of Ej, assumed that Hi has occurred.

3. PROBABILITY KNOWLEDGE BASE FOR "QL_CONST1"

The knowledge base (KB from now on) is generated upon "a priori" and conditional probabilities with the asistance of human experts in structural engineering and safety of structures. The degree of dependence in Ej (in this case, a small one) will affect all information for all hypotheses considered. Therefore, the overall conclusions reached by the system are quite reasonable, as expected. In QL_CONST1 (version I) three basic hypotheses are included up-to-date: GOOD, MEDIUM and POOR Quality Level (QL from now on). The hypotheses and evidences are codified into - the KB in natural language. Each one has a considerable number of evidences Ej - and a set of probabilites associated: $P(Hi)$ for the hypothesis itself and $P(Ej : Hi)$ and $P(Ej : \bar{H}i)$ for each one of the evidences related to the hypothesis. Evidences were classified into several groups, depending upon their source, which are: Visual inspection, Control of materials, Inspection "on site" and Project - and building planes.

Human experts could provide, with relative easyness and clarity, the "a priori" probability for each hypothesis, $P(Hi)$, and conditional probability for - the presence of Ej given that Hi has occurred, i.e. $P(Ej : Hi)$. However, the values of $P(Ej : \bar{H}i)$ were - much more difficult to give by experts than the previous ones. Nevertheless, it can be avoided by calculating them as described below. Let Ej be the new evidence introduced and Hi the hypothesis under consideration. The Universe U of hypotheses considered is show in figure 2, where we state:

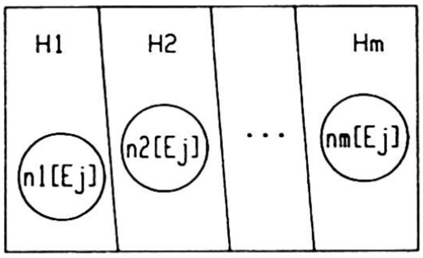


Fig. 2. Universe of Hi

$ni|Ej|$ = number of specimens (in hypothesis Hi) which presents evidence Ej (4)
ni = number of specimens in Hi
$N|Ej|$ = total number of specimens in U which presents Ej (5)
$\bar{N}|Ej|$ = total number of specimens in U which do not presents Ej
$N=N|Ej|+\bar{N}|Ej|$ = total number of specimens in U (6)

The probability for the presence of Ej in specimens belonging to Hi is:

$$P(Ej : Hi) = ni|Ej|/ni \; ; \quad i = 1,2,...,m \qquad (7)$$

The "a priori" probability for each hypothesis Hi could be written as:

$$P(Hi) = ni/N \; ; \quad i = 1,2,...,m \qquad (8)$$

In view of (4) and (5), we can write:

$$P(Ej : \bar{H}i) = \sum_{k \neq i}^{m} nk|Ej| \; / \sum_{k \neq i}^{m} nk \qquad (9)$$

By substituting (6) into (9) yields

$$P(Ej : \bar{H}i) = \sum_{k \neq i}^{m} nk|Ej| \; / \; (N-ni) \qquad (10)$$

By substituting (7) and (8) into (10) we obtain

$$P(Ej : \bar{H}i) = N \, . \sum_{k \neq i}^{m} P(Hk) \, . \, P(Ej : Hk) \; / \; (N-ni) \qquad (11)$$

By dividing (11) by N and remembering that $1-P(Hi = P(\bar{H}i)$, we finally arrive at:

$$P(Ej : \bar{H}i) = 1/P(\bar{H}i) \, . \sum_{k \neq i}^{m} P(Hk) \, . \, P(Ej : Hk) \qquad (12)$$

4. DESCRIPTION OF EXPERT SYSTEM "QL_CONST1"

The final goal is to obtain the probability of occurrence for the likely hypothesis Hi by including all the required evidences. The probability values are updated, by asking about the new evidences (let's, for instance, presence or not of shear cracks), until the system reaches a reliable conclusion. The way how the - User answers the system's questions is a topic of interest. In classic logic, - events either occur or do not occur, which implies that answers would be either true (1) or false (0). Nevertheless, in probabilistic processes (also in those - governed by Fuzzy Logic Theory [10]) knowledge is no longer either true or false, but has an associated degree of uncertainly.

Thus, when the system requests information about a certain evidence, it becomes necessary to allow the User to reply with phrases such as: "I don't know" (absolute uncertainty) or "more or less" (may be 'yes' but not really sure). So, - "QL_CONST1" accepts the user's answer in the form of a numerically graded scale, with values comprised between a negative integer (-5) and a positive one (+5). - The zero value represents absolute uncertainty.

5. EXPERT SYSTEM BEHAVIOUR ASSESSING AND RELIABILITY

The KB developed here was extensively tested and modified taking into consideration the suggestions from many human experts. Also, some critical situations were considered, giving satisfactory results, one of them will be shown and discussed further. In order to improve the sequence of computer questions, the Rule Value [4] was optimized together with a selective refinement of the probability values. This combined approach allows to obtain a questions' sequence more efficient and closer to human behaviour. This example assumes an hypothetical structure whose build-up process was made following high quality guidelines. A visual inspection was made giving excellent results, i.e., neither cracks, nor reinforce without - cover, etc. were observed. The following text reproduces exactly the messages and dialog between the user and the computer:

Please, answer questions with integer numbers as indicated in the scale below...

```
        -5              0              +5
        |---------------|---------------|
        NO         UNCERTAINTY         YES
```

QL_CONST1 : What about control of CONCRETE QUALITY?. Were there enough compression strength tests on cylinders?.

User : 5

QL_CONST1 : Were there COLUMNS outside its vertical line observed?

User : -5

QL_CONST1 : Were there FLEXURE CRACKS observed?

User : -5

QL_CONST1 : Were there SHEAR CRACKS in beams observed?

User : -5

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

QL_CONST1 : Were there qualified PERSONNEL to build-up the FORMS and to retire them?.

User : 5

QL_CONST1 : Were there qualified PERSONNEL to handle and place the reinforcement?

User : 5

QL_CONST1 : Were there any previous studies on SOIL BEHAVIOUR?

User : 5

===

My PREDICTION is: The structure has GOOD quality level with a probability of 99%

===

Now, it is necessary to demonstrate that expert system responses do not "jump" - around local intermediate situations. The set of evidences was divided into two main groups, namely: a) evidences related to knowledge about build-up process - (KDC group) including plans, details, materials control, etc., and b) evidences related to visual inspections, which will be identified as VIR from now on. Thus, for instance, figure 3 illustrates the system responses when KDC = -5, i.e., all

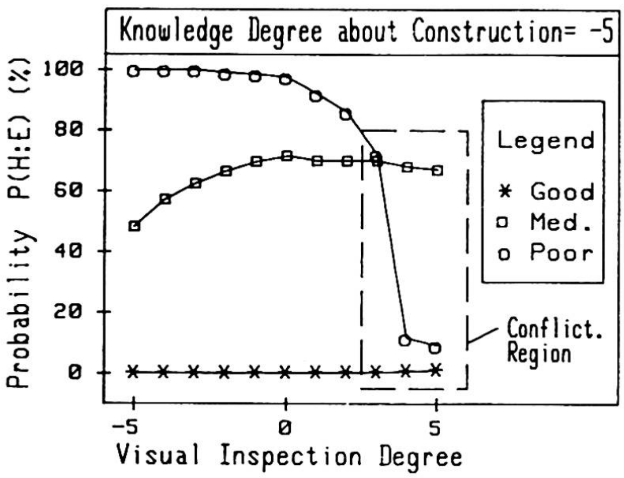


Figure 3. ES Responses (KDC = -5)

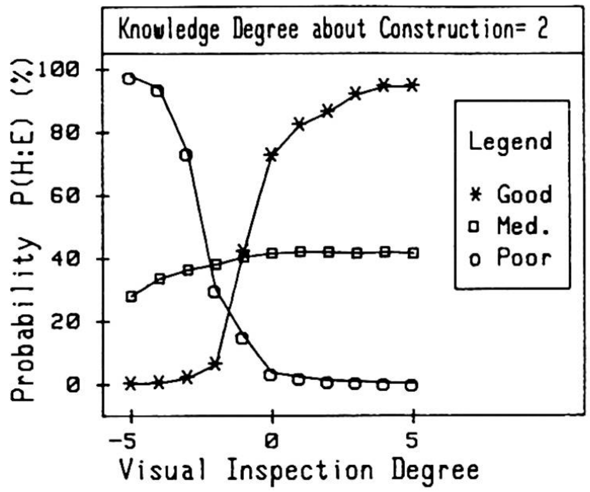


Figure 4. ES Responses (KDC = 2)

questions related to evidences comprised into the KDC group were answered with -5 (NO) in the case they were formulated towards GOOD quality structures and with +5 (YES) for questions formulated in the opposite direction. The vertical scale of - figures reflects the final conditional probability values for the hypotheses considered herein, whereas horizontal scale contains the VIR values given for all - questions related with evidences belonging to VIR group. Figure 3 represents a - subset of structures with KDC = -5, i.e. structures built following wretched guidelines with an "absolute certainty". As expected, the QL for such structures could never be GOOD and the system recognizes this fact. Also observe that, even in the presence of "more or less" satisfactory VIR values (say, until VIR=2) the system assigns the POOR grade, which could be seen as a conservative criterion. - For VIR values larger than 2, the system recognizes a real-world piece of - non-sense identified as a "conflictive region" in the figure: it is normally improbable that badly build-up processes could give acceptable QL structures. Figure 4 (KDC=2) shows the QL results - for a "moderate confidence" in a suitable build-up process. As expected, VIR parameter is again decisive to assign whatever qualification. Finally, figure 5 (KDC=5) constains the QL results for an "absolute certainty" in a suitable build-up process. Once again, the sys-

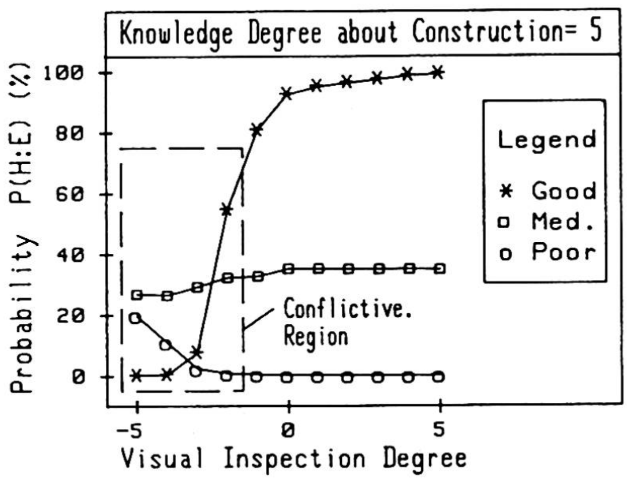


Figure 5. ES Responses (KDC = 5)

tems recognizes a real-world contradiction: it is not normally probable that - well-built specimens could exhibit either bad or calamitous final aspect.

As it can be observed, the system's performance follows a not "jitter" way, go- ing assimptotically towards numerical limits expected. From another point of - view, when comparing the system judgement to human experts ones, satisfactory - results were obtained. In most cases, human experts did not hesitate to claim - that they agree with the system answers inside a reasonable range.

6. CONCLUSIONS

A knowledge-based system prototype for Quality Level prediction in concrete struc tures has been presented. The KB developed here for structural quality assessing was extensively tested. It has show a satisfactory performance, even in the pre- sence of limit situations, and it is actually being increased by adding more pro bability based rules and by refining the set of hypotheses.

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