Computer Applications in Concrete Technology

Schlomo Ginsburg
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PREFACE

The primary goal of Committee 118 on Use of Computers is to serve as a source of know-how for the entire civil engineering community. In order to achieve this goal, it has been determined that Committee 118 should sponsor sessions on state-of-the-art computer applications in all areas of concrete design and technology.

The 1986 ACI annual convention featured, as a part of the primary purpose of committee 118 on Use of Computers, two sessions on state-of-the-art computer applications. Naturally, the formidable goal of the committee requires the careful selection of topics to be presented at conventions and published in symposium volumes. A wide spectrum of excellent papers was presented, covering topics in such areas as analysis, design, construction, education, and others. From finite elements to spreadsheet programming and expert systems, new ideas and techniques have been introduced.

This volume contains the full-length papers which were presented at the convention, plus one paper which was submitted especially for this volume.

The authors are gratefully acknowledged for contributing their talents and efforts. The quality of the sessions was also due to the tedious work of the reviewers, both from within Committee 118 and outside of it. The work of the former and present chairmen of Committee 118, and that of the ACI staff, is greatly appreciated. In particular, the following individuals have contributed to the success of these sessions:

David Darwin	Safwan Khedr	Carlos I. Pesquera
Jane Edmunds	David C. Kraft	William A. Price
Steven Fenves	James R. Libby	Mehdi Saiidi
Dan Frangopol	Christian Meyer	Charles G. Salmon
Kurt H. Gerstle	Joseph E. Moha	Floyd O. Slate
Cheng-Tzu Thomas Hsu	Edward G. Nawy	Stuart E. Swartz
Jose M. Izquierdo		Thomas H. Wenzel

Last, but not least, the technical assistance of Mondy Barlow, Stephanie Thompson, Ann Bruttell, and Robert Wiedyke in preparing and conducting the sessions, and in printing this volume is gratefully recognized.

Shlomo Ginsburg
Committee 118

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CONTENTS

Expert System for Selecting Concrete Constituents

By J.R. Clifton and B.C. Oltikar

Synopsis: A large amount of specialized factual and heuristic knowledge on the relations between the design of concrete mixtures, including the constituents, and the durability of concrete has been gained through research and field experience. Effective dissemination of this knowledge should result in fewer incidents of premature deterioration of concrete. Expert systems appear to be an effective means for transferring the knowledge on the durability of concrete obtained through laboratory and field studies and experiences to engineers and designers responsible for the design, construction, and maintenance of concrete structures.

Durcon is a prototype expert system being developed to give recommendations on the selection of constituents for durable concrete. The purpose of developing Durcon is to demonstrate the application of expert systems to improve the process of selecting construction materials. Four major deterioration problems are covered by Durcon, freezing and thawing, corrosion of reinforcing steel, sulfate attack, and alkali-aggregate reactions. This report discusses the approach being followed and the progress being made in developing Durcon. In addition, model systems for recommendations for concrete exposed to corrosive environments and for preventing alkali-aggregate reactions are presented.

Keywords: aggregates; alkali-aggregate reactions; artificial intelligence; computer programs; concrete durability; corrosion; freeze-thaw durability; mix proportioning; sulfate attack.

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INTRODUCTION

Although extensive research has been carried out on the deterioration of concrete, persistent problems still occur with the durability of concrete structures. For example, the corrosion of reinforcing steel in concrete is a widespread occurrence in concrete structures exposed to chloride ions from deicing salts or seawater. Extensive research on corrosion of steel reinforcement has been carried out which has greatly increased the understanding of the factors affecting the corrosion processes. Similarly, extensive research has been carried out on other major deterioration problems, such as the freeze-thaw durability of concrete, sulfate attack of concrete, and deleterious reactions between alkalies in concrete and reactive aggregates. If the results of these and future research are properly disseminated, then fewer incidents of premature deterioration in new concrete structures should be observed.

Expert systems, also known as knowledge-based systems, appear to be an effective means for transferring the knowledge on the durability of concrete gained through research and field experience to individuals responsible for the design, construction, and maintenance of concrete structures. Expert systems are considered to be computer programs that use knowledge and inference procedures to solve problems that are difficult enough to require significant human expertise for their solution (1). The knowledge of most current expert systems consist of facts and heuristics. Facts constitute information that is widely accepted to be valid and readily available (e.g., in textbooks or ASTM standards). Heuristics are rules-of-thumb or good judgement that an expert would use to solve a problem when well-understood theories or facts are not available (2).

PRINCIPLES OF EXPERT SYSTEMS

An overview of expert systems is presented in this section to introduce the concepts involved in the development of Durcon. More comprehensive views of expert systems are given in references 3, 4, and 5.

Features of Expert Systems

In the several definitions given for the term "expert system," the essential concept expressed is the use of the knowledge of experts to solve difficult problems. Feigenbaum (1), a pioneer in expert systems, gave the following definitions in which the main concepts are presented:

> "An Expert System is an intelligent computer program that uses knowledge and inference procedures to solve problems that are difficult enough to require significant human expertise for their solution. The knowledge necessary to perform at such a level, plus the inference procedure used, can be thought of as a model of the expertise of the best practitioners in the field."

Architecture of an Expert System

An expert system is an interactive system consisting of three major components (Figure 1):

(1) A knowledge base of facts and heuristics which can be applied to a specific case.

(2) A global data base (working memory) which contains, in temporary storage, observations or evidence provided by the user about a specific case, and all derived information about the case.

(3) A control system or inference engine which selects the appropriate knowledge rules and recommendations for the solution of the problem.

Other features usually present in expert systems are:

* explanatory interface which permits the user to understand why certain questions are asked and gives a justification for specific conclusions or recommendations

* transparency of the computer program to the user (i.e., the user does not become involved in programming).

* modification of the computer program can be accomplished without a comprehensive re-programming, e.g., portions of the knowledge base can be modified without the need for other restructuring.

Knowledge Base

The ability of an expert system to solve a problem (referred to as its "power") has been observed to increase with the extent of its domain (subject specific) knowledge. Undoubtedly the most demanding phase of developing an expert system is obtaining and representing relevant knowledge.

The domain knowledge of an expert system is often represented by production rules which have the general form:

If: Logical conditions are satisfied (antecedent)
Then: Take the indicated action (consequence)

These rules are further illustrated by the following rule taken from Durcon:

If: (1) Severe freeze-thaw conditions are anticipated and
(2) The nominal size of aggregate is 3/8 inch (9.5 mm.)
Then: The percent of entrained air should be 7.5

An expert system usually has many judgmental or empirical rules (heuristics) which lead to recommendations or conclusions which contain a certain level of uncertainty. In some expert systems, a numerical value (certainty factor) are given to each rule to indicate the degree of certainty. These certainty factors can be combined with each other to obtain an overall certainty factor for the final recommendation or conclusion. Certainty factors are measures of the confidence that can be placed in any given conclusion or recommendation. The present version of Durcon does not include certainty factors because in the approach taken to develop all rules are considered to have a certainly factor of unity.

Control System

The control system decides which production rules should be invoked and it must resolve any conflicts which may occur if several rules are satisfied. There are two main approaches for evaluating production rules: backward chaining and forward chaining (3,5).

In backward chaining the system has a set of initial goals, such as solutions to a problem. The rules are invoked in reverse order, with the right-hand sides of the rules stating possible goals, and the left-hand side of the rules being examined to determine which goals are satisfied i.e., consistent with the evidence. The goals are proven or disproven until the "most-correct" solution is obtained. Backward chaining is often used in diagnostic systems e.g., MYCIN (6).

In forward chaining the system does not start with any defined goals. Instead, the system starts with a set of evidence and proceeds to invoke the rules in a forward direction (antecedent first), continuing until no further production rules can be invoked. Forward chaining is often used in systems providing recommendations on design related problems.

APPROACH FOR DEVELOPING DURCON

The knowledge base for expert systems is usually created as the result of interrogating an expert or a small team of experts by the knowledge engineer. In the development of the knowledge base for Durcon, a different approach is being taken. The "Guide to Durable Concrete," prepared by the ACI@ (American Concrete Institute) Committee 201 on Durable Concrete (7) was chosen to be the factual component of the knowledge base. This document was selected because the facts it contains should have widespread credibility among the concrete community. In the conceptual design of Durcon, four major durability problems covered by the Guide were considered, corrosion of reinforcing steel, freezing and thawing, sulfate attack, and reactions between the constituents of cement and aggregates. These four problems were selected because they comprise the most persistent causes of the premature deterioration of concrete. The major factors controlling the response of concrete to these deterioration processes and recommendations of measures to minimize their deleterious effects are given in the Guide. In addition to the ACI Guide, appropriate ASTM standards, guidelines by the U.S.

Army Corps of Engineers, and Navy construction documents have been reviewed.

The first step in representing the factual knowledge used in Durcon was the creation of tree (hierarchy) structures. The tree structure for the knowledge of the corrosion of reinforcing steel is illustrated in

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Figure 2. Then the facts were expressed in the form of production rules.

The sequences of the stages in developing Durcon is indicated in Figure 3. A subcommittee has been established in ACI Committee 201 for the purpose of critiquing Durcon and recommending what factual and heuristic knowledge should be added. Further improvements in the knowledge undoubtedly will result from user's evaluation during problem solving sessions.

MODEL SYSTEMS

Model systems have been developed for the four durability problems being addressed by Durcon. These model systems are largely based on the information contained in The ACI Guide to Durable Concrete (7), and they will be revised according to the recommendations from the Committee members and comments by users. The specific user inputs and recommendations given by each model system are listed in Tables 1-4. Because Durcon is still being developed, the model systems are for demonstrative purposes only and they, undoubtedly, will undergo significant enhancements.

Features of Systems

The model expert systems use production rules as described in the Knowledge Base section. Their control systems support a forward-chaining procedure (3). The programs are written in PASCAL and operate on the IBM PC (personal computer) or compatible, using the IBM PC disk operating system (DOS). The freeze-thaw, corrosion, and sulfate durability systems are contained on one diskette and require 256 KB of memory to operate. The alkali-aggregate system is on a separate diskette and requires a memory of 512 KB to operate. In the next major revision of Durcon, it will be restructured using an expert system shell which probably will permit the four durability systems to be contained on a single diskette.

Examples of Sessions

A users session with the corrosion knowledge base is presented in Table 5 and a session with the alkali-aggregate knowledge base is presented in Table 6. Note that with both systems, a user can request an explanation of both questions and of recommendations. A model system using the freeze-thaw knowledge base was previously published (8).

APPLICATIONS OF EXPERT SYSTEMS

Durcon addresses the selection of constituents and the design of concrete mixtures. Diagnostics and maintenance of reinforced concrete structures are areas in which expert systems should provide significant benefits. Diagnostics would include field inspection and laboratory analyses of concrete, the determination of the extent of deterioration, and the identification of the causes of deterioration. A system on maintenance would provide recommendations on the type and extent of repairs needed.

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Table 1. Corrosion Resistance of Reinforced Concrete: Specific Case Information and Recommendations

Specific Case Information[a]	Recommendations[b]
1. Environment: indoor or outdoors	1. Concrete cover over reinforcement
2. Indoor environment: little or no exposure to moisture, occasional, or regular exposure to moisture	2. Concrete permeability
	3. Water to cement ratio
3. Outdoor environment: sea or saltwater, arid climate, or normal to high precipitation	4. Chloride ion content
	5. Concrete quality
4. Sea or saltwater exposure: splash zone, or continuous submergence	
5. Chloride ion exposure: mild, moderate, or severe	
6. Reinforcement type: steel bars or prestressed steel	

[a] Information provided by user on specific case being considered.

[b] Recommendations by Durcon based on specific case information.

Table 2. Freeze-Thaw Durability: Specific Case Information and Recommendations

Specific Case Information[a]	Recommendations[b]
1. Type of cement: portland or blended	1. Water to cement ratio
2. Type of concrete: normal weight or lightweight	2. Amount of entrained air
3. Concrete member: thin section or normal section	3. Compressive strength
4. Exposure conditions: dry, moderate, or severe	4. Acceptibility of aggregate
5. Type of aggregate: natural aggregate or lightweight	5. Applicable ASTM standards and test procedures
6. Aggregate size	
7. Selection of admixture	

[a] Information provided by user on specific case being considered.

[b] Recommendations by Durcon based on specific case information.

Table 3. Sulfate Resistance: Specific Case Information and Recommendations

Specific Case Information[a]	Recommendations[b]
1. Exposure conditions: sulfate in soil or water	1. Water to cement ratio
2. Severity of exposure: sulfate contents of soil or water	2. Type of either portland or blended cement
3. Type of cement: portland or blended	3. If fly ash added: type of fly ash, and amount of fly ash added
4. Will fly ash be added to concrete?	4. Compressive strength
5. Type of concrete: normal weight or lightweight	5. Applicable ASTM standards

[a] Information provided by user on specific case being considered.

[b] Recommendations by Durcon based on specific case information.

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