7-Conclusions and Discussions

In this paper, the applicability of Expert Systems (ES) for diagnosis the deterioration of concrete structures was investigated. Then, we developed an ES prototype for this purpose. It is shown that ES can better represent this problem than the classical methods. Moreover, the inference engine module can reason the real situation similar to the human behavior. This helps us to solve the problem more robust without eliminating any variable or constraint. Moreover, since the structure of the system is logical oriented, the implementation of the system is easier and more user friendly for the users.

There are some potential future works for this research. The presented system provides diagnosis of common problems specially cracks cause in reinforced concrete. However, the variables and operators in this system were crisp. Development of a fuzzy expert system for this domain is a potential future work.

References

[1] Strecker, P. P., "Corrosion Damage Concrete: assessment and repair", *Construction Industry Research and Information Association*, Butterworths, London, 1987.

[2] Russell S. J., and Norving J., "Artificial Intelligence: A Modern Approach", Prentice-Hall, 1995.

[3] Adeli, H., "Artificial Intelligence in Structural Engineering", *Engineering Analysis*, Vol. 3, No. 3, 1986, pp. 154-60.

[4] Elias, A. L., "Computer-aided engineering: AI connection", *Astronautics and Aeronautics*, A.I.A.A., July-August, 1983, pp. 48-54.

[5] Dixon, J. R. and Simmons, M. K., "Computers that Design: Expert System for Mechanical engineers", *Computers and Structures*, Vol. 6 1983, pp. 325-331.

[6] Finn, G. A., "Expert Systems in an Engineering/Construction Firm" *Proceeding of the ASCE Symposium on Expert Systems in Civil Engineering*, Seattle, Washington.

[7] Adeli, H. "Expert Systems in Construction and Structural Engineering", Chapman and Hall, 1988, Bristol, UK.

[8] Allen, R. H., "Expert Systems for Civil Engineers: Knowledge Representation", *ASCE Expert System Committee*, 1992, New York, USA.

[9] Zhuo, Y. and Yangbioa, S. "An Expert Systems for Shape Optimum Design of Parabola Arch Dams", *International Journal of Engineering :Iran University of Since and Technology*, Vol. 4, No.1a, 1993, pp13-20.

[10] Salvaneschi, P. Cadei, M. and Lazzari, M. "Applying AI to Structural Safety Monitoring and Evaluation", *IEEE Expert*, August, 1996, pp. 24-34.

[11] Ritchie, S.G. and Harris, R.A., "Expert Systems for Civil Engineers: Technology and Application", *ASCE*, New York, NY, 1987.

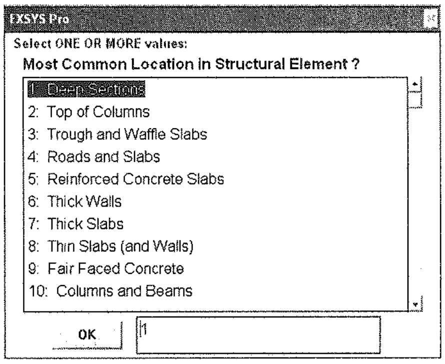
[12] Ross, T. J., Sorensen, C., Savage, J., and Carson, J. M., ''DAPS: Expert system for damage assessment.'' *Journal of Computing in Civil Engineering*. ASCE, No.4 Vol.4, 1990, pp. 327–348.

[13] Durkin J., "Expert Systems: Design and Development", Macmillan Publishing Company, 1994.

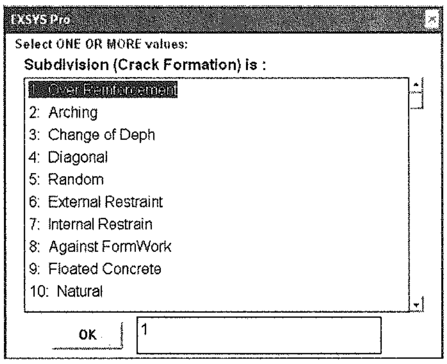
[14] EXSYS, EXSYS Inc. Albuq. NM.

[15] Raina, V. K., "Concrete Bridges: Inspection, Repair, Strengthening, Testing and Load Capacity Evaluation", Tata McGraw-Hill, New Delhi, 1994.

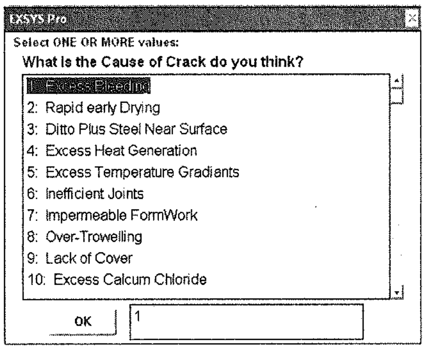
[16] Neville, A.M., "Properties of Concrete", the English Language Book Society, Pitman Publishing, 1977.



(i)

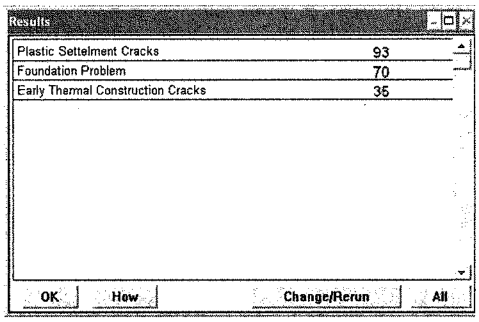


(j)

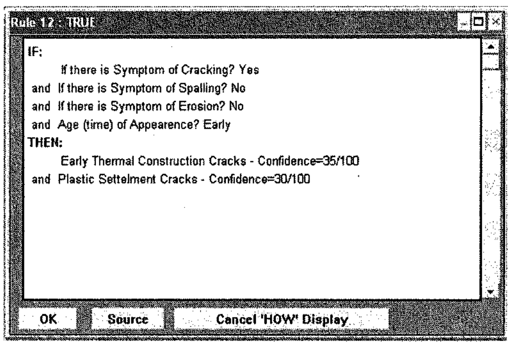


(k)

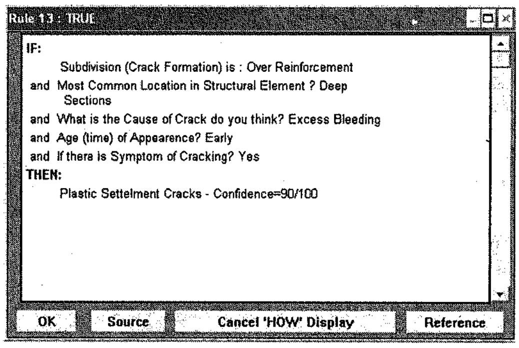
Figure (6) (cont.)



(a)



(c)



(d)

Figure (7) (a) Example test conclusion with certainty numbers
(b, c) Explanation how conclusion was gained.

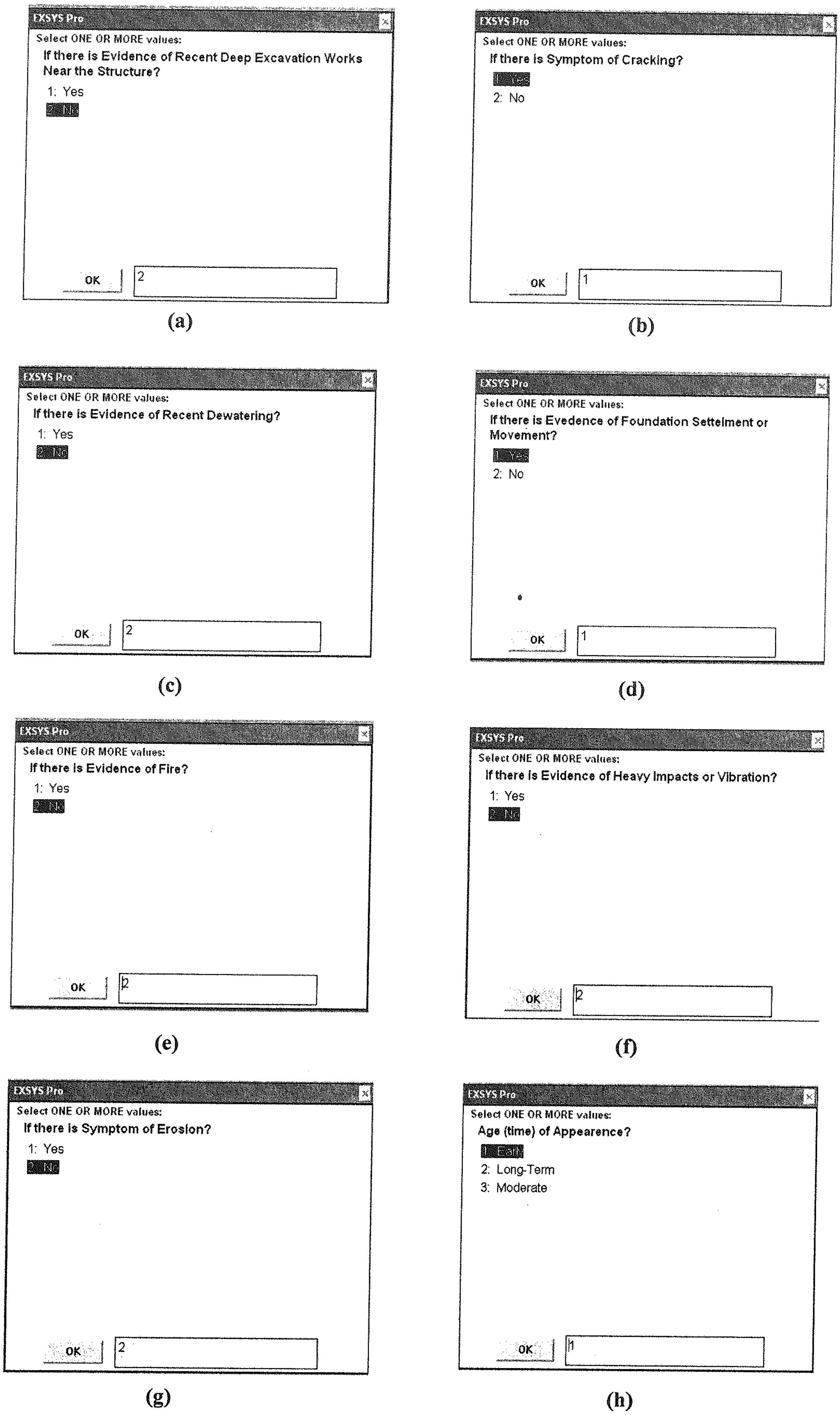


Figure (6) Expert system verification.

RULE NUMBER: 24

IF:
If there is Symptom of Cracking? Yes
and Age (time) of Appearance? Long-Term
and Subdivision (Crack Formation) is: Natural
and Most Common Location in Structural Element? Columns and Beams
and What is the Cause of Crack do you think? Lack of Cover
THEN:
Cracks due to Corrosion of Reinforcement-Confidence=90/100

RULE NUMBER: 25

IF:
If there is Symptom of Cracking? Yes
and Age (time) of Appearance? Long-Term
and Subdivision (Crack Formation) is: Calcium Chloride
and Most Common Location in Structural Element? Precast Concrete
and What is the Cause of Crack do you think? Excess Calcium Chloride
THEN:
Cracks due to Corrosion of Reinforcement-Confidence=90/100

RULE NUMBER: 26

IF:
If there is Symptom of Cracking? Yes
and Age (time) of Appearance? Long-Term
and Subdivision (Crack Formation) is : Unknown
and Most Common Location in Structural Element? Damp Location
and What is the Cause of Crack do you think? Reactive Aggregate plus High Alkali Cement
THEN:
Cracks due to Alkali-Aggregate Reaction-Confidence=97/100

6-Verification and Validation

The proposed Expert System was tested with a case study. In Table V, we summarize evidence of problem in this case study.

Table (V) Summary of observed problem based on Expert System guideline.

Type of problem in element	Existence of problem in current case
Crack	✓
Recent deep excavation works near the structure	×
Recent dewatering	×
Foundation settlement or movement	✓
Fire problem	×
Heavy impact or vibration	×
Erosions	×

In Table VI, the characteristics of damage in element are summarized according to question and answer of the presented Expert System.

Table (VI) Summary of the details of damage.

Age of appearance of the damage	Early
Crack formation	Over reinforcement
Location of damage in structure	Deep section

Figure 6 demos the questions-answers that are exchanged between Expert System and user. In figure 6-a, the system asks user about evidence of cracking in the structural member. In this part, the system validate rule number 1. Interface shown in figure 6-b validates the second premise of rule number 1. Figures 6-c to 6-f relate to rules number 2, 3, 4, and 5 respectively. These rules ask information about some reason of element's defect. Reminded figures (6-g to 6-k) are another oriented questions that system asks from the user based on previous question-answers.

Figure 7-a, shows that three conclusion are deduced from the above Question-Answer approach. As shown in Figure 7-b and 7-c, these conclusions are extracted from rules 17 and 13 (see rule-base) by firing their premises into Question-Answerer process and adding them in the working memory.

Plastic Settlement Cracks - Confidence=90/100

RULE NUMBER: 15

IF:
If there is Symptom of Cracking? Yes
and Subdivision (Crack Formation) is: Change of Deph
and Most Common Location in Structural Element? Trough and Waffle Slabs
and What is the Cause of Crack do you think? Excess Bleeding
and Age (time) of Appearance? Early
THEN:
Plastic Settlement Cracks - Confidence=90/100

RULE NUMBER: 16

IF:
If there is Symptom of Cracking? Yes
and Subdivision (Crack Formation) is: Diagonal
and Most Common Location in Structural Element? Roads and Slabs
and What is the Cause of Crack do you think? Rapid early Drying
THEN:
Plastic Shrinkage Cracks - Confidence=90/100

RULE NUMBER: 17

IF:
If there is Symptom of Cracking? Yes
and Age (time) of Appearance? Early
and Subdivision (Crack Formation) is: Random
and Most Common Location in Structural Element? Reinforced Concrete Slabs
and What is the Cause of Crack do you think? Rapid early Drying
THEN:
Plastic Shrinkage Cracks - Confidence=90/100

RULE NUMBER: 18

IF:
If there is Symptom of Cracking? Yes
and Age (time) of Appearance? Early
and Subdivision (Crack Formation) is: Over Reinforcement
and Most Common Location in Structural Element? Reinforced Concrete Slabs
and What is the Cause of Crack do you think? Ditto Plus Steel Near Surface
THEN:
Plastic Shrinkage Cracks - Confidence=90/100

RULE NUMBER: 19

IF:
If there is Symptom of Cracking? Yes
and Age (time) of Appearance? Moderate
and Subdivision (Crack Formation) is: External Restraint
and Most Common Location in Structural Element? Thick Walls
and What is the Cause of Crack do you think? Excess Heat Generation
THEN:
Early Thermal Construction Cracks- Confidence=90/100

RULE NUMBER: 20

IF:
If there is Symptom of Cracking? Yes
and Age (time) of Appearance? Moderate
and Subdivision (Crack Formation) is: Internal Restrain
and Most Common Location in Structural Element? Thick Slabs
and What is the Cause of Crack do you think? Excess Temperature Gradiants
THEN:
Early Thermal Construction Cracks- Confidence=90/100

RULE NUMBER: 21

IF:
If there is Symptom of Cracking? Yes
and Age (time) of Appearance? Long-Term
and Subdivision (Crack Formation) is: Unknown
and Most Common Location in Structural Element? Thin Slabs (and Walls)
and What is the Cause of Crack do you think? Inefficient Joints
THEN:
Long-Term Drying Shrinkage Cracks- Confidence=90/100

RULE NUMBER: 22

IF:
If there is Symptom of Cracking? Yes
and Age (time) of Appearance? Long-Term
and Subdivision (Crack Formation) is: Against Formwork
and Most Common Location in Structural Element? Fair Faced Concrete
and What is the Cause of Crack do you think? Impermeable Formwork
THEN:
Crazing Cracks - Confidence=90/100

RULE NUMBER: 23

IF:
If there is Symptom of Cracking? Yes
and Age (time) of Appearance? Long-Term
and Subdivision (Crack Formation) is: Floated Concrete
and Most Common Location in Structural Element ? Roads and Slabs
and What is the Cause of Crack do you think? Over-Trowelling
THEN:
Crazing Cracks - Confidence=90/100
----

and If there is Evidence of Foundation Settlement or Movement? Yes
THEN:
Foundation Problem - Confidence=70/100

RULE NUMBER: 4

IF:
If there is Symptom of Cracking? Yes
and If there is Evidence of Fire? Yes
THEN:
Fire Damage - Confidence=90/100

RULE NUMBER: 5

IF:
If there is Symptom of Cracking? Yes
and If there is Evidence of Heavy Impacts or Vibration? Yes
THEN:
Physical Damage - Confidence=90/100

RULE NUMBER: 6

IF:
If there is Symptom of Cracking? Yes
and If there is Symptom of Spalling? Yes
and If there is Symptom of Erosion? Yes
and Age (time) of Appearance? Early
and Age (time) of Appearance? Long-Term
THEN:
Physical Damage - Confidence=30/100
and Frost Damage - Confidence=35/100

RULE NUMBER: 7

IF:
If there is Symptom of Cracking? Yes
and If there is Symptom of Spalling? Yes
and If there is Symptom of Erosion? Yes
and Age (time) of Appearance? Long-Term
THEN:
Chemical Attack - Confidence=85/100

RULE NUMBER: 8

IF:
If there is Symptom of Cracking? Yes
and If there is Symptom of Spalling? Yes
and If there is Symptom of Erosion? No
and Age (time) of Appearance? Long-Term
THEN:
Creep Problem - Confidence=35/100
and Internal Reactions Problem-Confidence=35/100
and Reinforcement Corrosion Damage-Confidence=35/100

RULE NUMBER: 9

IF:
If there is Symptom of Cracking? Yes
and If there is Symptom of Spalling? Yes
and If there is Symptom of Erosion? No
and Age (time) of Appearance? Early
and Age (time) of Appearance? Long-Term
THEN:
Thermal Effect Problem - Confidence=60/100

RULE NUMBER: 10

IF:
If there is Symptom of Cracking? Yes
and If there is Symptom of Spalling? Yes
and If there is Symptom of Erosion? No
and Age (time) of Appearance? Early
THEN:
Fire Damage - Confidence=40/100
and Structural Deficiency Problem-Confidence=50/100

RULE NUMBER: 11

IF:
If there is Symptom of Cracking? Yes
and If there is Symptom of Spalling? No
and If there is Symptom of Erosion? No
and Age (time) of Appearance? Early
and Age (time) of Appearance? Long-Term
THEN:
Shrinkage Problem - Confidence=60/100

RULE NUMBER: 12

IF:
If there is Symptom of Cracking? Yes
and If there is Symptom of Spalling? No
and If there is Symptom of Erosion? No
and Age (time) of Appearance? Early
THEN:
Early Thermal Construction Cracks-Confidence=35/100
and Plastic Settlement Cracks - Confidence=30/100

RULE NUMBER: 13

IF:
Subdivision (Crack Formation) is: Over Reinforcement
and Most Common Location in Structural Element? Deep Sections
and What is the Cause of Crack do you think? Excess Bleeding
and Age (time) of Appearance? Early
and If there is Symptom of Cracking? Yes
THEN:
Plastic Settlement Cracks - Confidence=90/100

RULE NUMBER: 14

IF:
If there is Symptom of Cracking? Yes
and Subdivision (Crack Formation) is: Arching
and Most Common Location in Structural Element? Top of Columns
and What is the Cause of Crack do you think? Excess Bleeding
and Age (time) of Appearance? Early
THEN:

			Table (IV) Continiue				
	F	Over reinforce ment	Reinforced concrete slabs	Ditto plus steel near surface			
Early Thermal Contraction Cracks	G	External restraint	Thick walls	Excess heat generation	Rapid cooling	Reduce heat and/or insulate	One day to two or three weeks
	H	Internal restraint	Thick slabs	Excess temperature gradients			
Long-term Drying Shrinkage Cracks	I		Thin slabs (and walls)	Inefficient joints	Excess shrinkage Inefficient curing	Reduce water content Improve curing	Several weeks of months
Crazing Cracks (occur only on surface)	J	Against formwor k	Fair faced concrete	Impermeable formwork	Rich mixes Poor curing	Improve curing and finishing	One to seven days sometim es much later
	K	Floated concrete	Slabs	Over- trowel ling			
Cracks due to Corrosion of reinforceme nt (expansive reaction can lead to spalling of concrete)	L	Natural	Columns and beams	Lack of cover	Poor quality concrete	Eliminate causes listed	More than two years
	M	Calcium chloride	Precast concrete	Excess calcium chloride			
Cracks due to Alkali-aggregate reaction (expansive reaction)	N		(Damp locations)	Reactive aggregate plus high alkali cement		Eliminate causes listed	More than five years

Thus, the rules of the proposed expert system for damage assessment of reinforced concrete structures are as follows:

RULE NUMBER: 1

IF:

If there is Symptom of Cracking? Yes

and If there is Evidence of Recent Deep Excavation Works Near the Structure? Yes

THEN:

Foundation Problem - Confidence=42/100

RULE NUMBER: 2

IF:

If there is Symptom of Cracking? Yes

and If there is Evidence of Recent Dewatering? Yes

THEN:

Foundation Problem - Confidence=40/100

RULE NUMBER: 3

IF:

If there is Symptom of Cracking? Yes

Table (III) Overall consideration of the common structural problems [15].

SYMPTOMS			AGE OF APPEARANCE		Conclusion
Cracking	Spalling	Erosion	Early	Long-term	
*	*	*	*	*	Physical Damage / Frost Damage
*	*	*		*	Chemical Attack
*	*			*	Creep / Internal Reactions / Reinforcement Corrosion
*	*		*	*	Thermal Effects
*	*		*		Fire Damage / Structural Deficiency
*			*	*	Shrinkage
*			*		Rapid Drying / Plastic Settlement

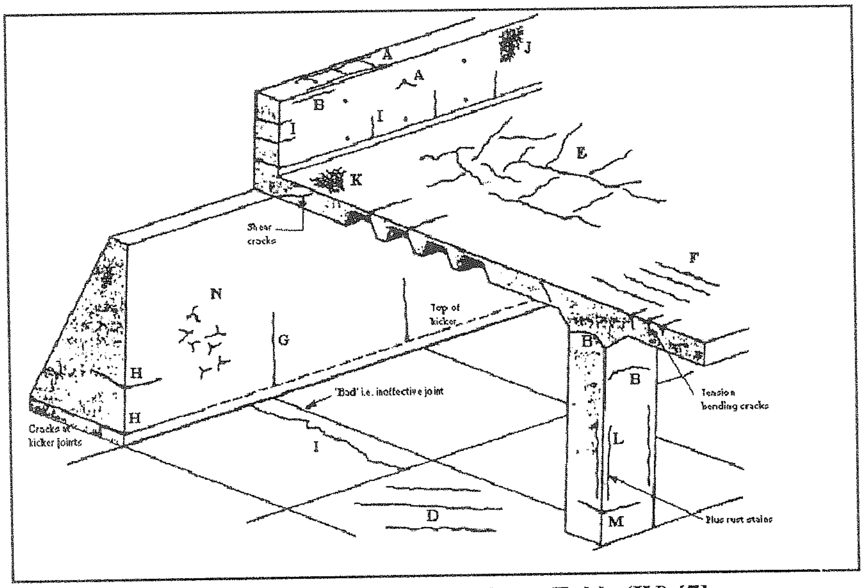


Figure (5) Crack patterns refer to Table (IV) [7].

Table (IV) Rules deal with combinations of evidence of crack formation and location on structures [15,16].

Type of Intrinsic Cracking (not caused by structural	*Letter Legend (see Fig. 4)*	*Subdivision (crack Formation)*	*Most common location (Structural Element)*	*Primary Cause(excluding restraint)*	*Secondary Cause/Factors*	*Remedy, Assuming Basic Redesign is Impossible (In all cases*	*Time of appearance*
Plastic Settlement Cracks	**A**	Over reinforcement	Deep sections	Excess bleeding	Rapid early drying conditions	Reduce bleeding (air entrainment) or revibrate	Ten minutes to three hours
	B	Arching	Top of columns				
	C	Change of depth	Trough and waffle slabs				
Plastic Shrinkage Cracks	**D**	Diagonal	Roads and slabs	Rapid early drying	Low rate of bleeding	Improve early curing	Thirty minutes to six hours
	E	Random	Reinforced concrete slabs				

The steel bars is near to the concrete surface: True
Rule 3 fires
Crack is of plastic shrinkage type CONCLUDE (Add to Working Memory)
Thus, this new finding is added into the working memory:

Working Memory

1. Age of concrete is 5 hour
2. The weather is hot
3. Speed of wind is high
4. Bleeding of concrete is low
5. The steel bars is near to the concrete surface
6. Concrete drying is rapid
7. Crack is of plastic shrinkage type

Then, the inference engine deduces that:

Conclusion: ***crack is of plastic shrinkage type***

This method of deduction is forward-chaining rule based expert system. In this paper we try to develop an expert system for diagnosis of concrete faults and problems. The approach that we use to this problem is similar to the example that was presented above.

5-System Design and Rule Definition

The knowledge domain should be organized so that the information can be structured in the computer program for effective use. The scope of this research is to integrate inspections and observations, specifications, standards of practice, and data related to reinforced concrete diagnosis and to make full use of the available information in the diagnosis process. The Expert System (ES) focuses on integrating inspection of commonly encountered problems, specifications, standards of practice and data, and both theoretical and empirical, into one cohesive tool. To develop such an expert system, EXSYS Expert System software version 5 has been implemented [14].

This paper concentrates on exposure of crack in the (Reinforced Concrete) R/C members. The rules are built from the following decision tables (Table II, III, IV).

As an example, rule 1 extracted from table (II):

IF There is Symptom of cracking
AND There is Evidence of fire
THEN Fire damage problem occurred.

Table (II) Common evidence of problems associated with the symptom of cracking [15]

Symptom of cracking	Evidence of recent dewatering	Evidence of recent deep excavation works near the structure	Evidence of foundation settlement or movements	Evidence of fire	Evidence of heavy impacts or vibration	Conclusion
*	*					Foundation Problems
*		*				Foundation Problems
*			*			Foundation Problems
*				*		Fire Damage
*					*	Physical Damage

The above fact are entered into the working memory:

Working Memory

1. Age of concrete is 5 hour
2. The weather is hot
3. Speed of wind is high
4. Bleeding of concrete is low
5. The steel bars is near to the concrete surface

The procedure of firing rules is as follows:
Rule 1, premise 1
The wind speed is high: True
Rule 1, premise 2
The weather is hot: True
Fire rule 1
Concrete drying is rapid CONCLUDE (add to Working Memory)

Thus, the working memory is updated as follows:

Working Memory

1. Age of concrete is 5 hour
2. The weather is hot
3. Speed of wind is high
4. Bleeding of concrete is low
5. The steel bars is near to the concrete surface
6. concrete drying is rapid

The system tries to see if a new rule can be fired:
Rule 2, premise 1
The age of concrete is 10 minutes to 3 hours: Unknown
Rule 2, premise 2
The bleeding of concrete is high: False
Rule 2 can not fire
At this step working memory is unchanged.

Working Memory

1. Age of concrete is 5 hour
2. The weather is hot
3. Speed of wind is high
4. Bleeding of concrete is low
5. The steel bars is near to the concrete surface
6. Concrete drying is rapid

Again the system tries to see if any rule can be fired:
Rule 3, premise 1
The age of concrete is 30 minutes to 6 hours: True
Rule 3, premise 2
The bleeding of concrete is low: True
Rule 3, premise 3
Initial state of drying is rapid: True
Rule 3, premise 4
The steel bars is near to the concrete surface: True
Rule 3, premise 5

control it's weakness of tensile strength. This composite material is named as "*reinforced concrete*". At first, when reinforced concrete is used for construction industry, its strength is the main concern and there is no deal with its durability. However, with passing time, these structures have shown their weakness and faults due to condition of where these structures are constructed: Spalling, scaling, pop out, peeling, cracking, etc., may appear on the surface of concrete. These problems have different reasons such as sulfate and chloride ion attacks, carbonation, and biological attack [1]. Every year, many papers are published by scientists about reasons of concrete faults and concrete durability problems. This paper introduces an expert system for detection of the reasons of concrete problems. Obviously taking into account the whole knowledge in such a system is a difficult task and needs a group of specialist in the field of civil and knowledge engineering. However, in this research, we try to develop a prototype of expert system in this area.

4- Problem Solving Approach

In general, when an expert encounters the problem with concrete, s/he sets up series of visual inspections. With her/his expertise, experience and similar cases, the knowledge about a problem is extracted. An expert uses different rules that are organized in her/his brain for diagnose and detects the faults in this field. For example, when an expert sees any map cracking on the surface of the concrete member, s/he considers probable alkali-aggregate reaction in concrete mass. Therefore, the expert has a knowledge base in her/his brain in the form of IF-THEN rules. With observation of any evidence, s/he acquires facts about the problem. Afterward, with comparison of these facts with knowledge saved in her/his brain, s/he deduces some conclusion about problem solution. The following simple example shows this problem solution approach. Suppose that an expert has some knowledge about concrete diagnosing problem, which is represented in the form of IF-THEN rules as follows:

1-IF <the wind speed is high> and <the weather is hot> THEN <concrete drying is rapid>.
2-IF <the age of concrete is 10 minutes to 3 hours> and <the bleeding of concrete is high> and <initial state of drying is rapid> THEN <crack is of plastic settlement type>.
3-IF <the age of concrete is 30 minutes to 6 hours> and <the bleeding of concrete is low> and <initial state of drying is rapid> and <the steel bars is near to the concrete surface> THEN <crack is of plastic shrinkage type>.

Suppose that the expert considers a problem about concrete. S/he gains the following facts about the problem:

1-Age of concrete is 5 hour
2-The weather is hot
3-Speed of wind is high
4-Bleeding of concrete is low
5-The steel bars is near to the concrete surface

With acquiring these facts about the problem, the expert refers to her/his knowledge base. S/he reviews the knowledge and deduces some conclusions. This process is demonstrated in Figure 4 [13].

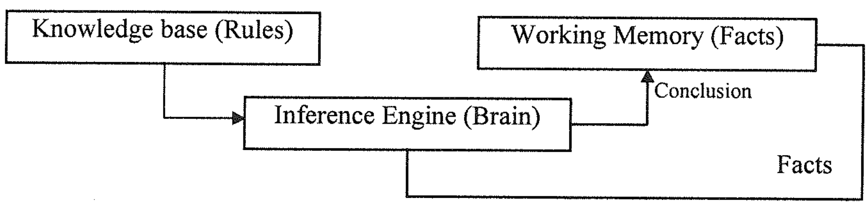


Figure (4) Problem solving model.

-allow objects to be defined and relationships drawn to other objects
-integrate different forms of knowledge
-increase the knowledge engineer's productivity

Two major components of an object are: *class* and *instance*. The class component defines the object properties and attributes. The instance contains the knowledge values. For example, a class called "distress" may be established. This class may be further divided into two subclasses for materials related distresses and in-service related distresses. The members of these subclasses share the characteristics and behavior of the class "distress". The attributes of a class involve facets, methods, rules, and demons. These affect the behavior and control of the class. Object-oriented programming has become a popular method for developing computer softwares and is becoming more popular in representing knowledge.

Figure 3, shows an example of object-oriented knowledge structure for cracking of the reinforced concrete structures.

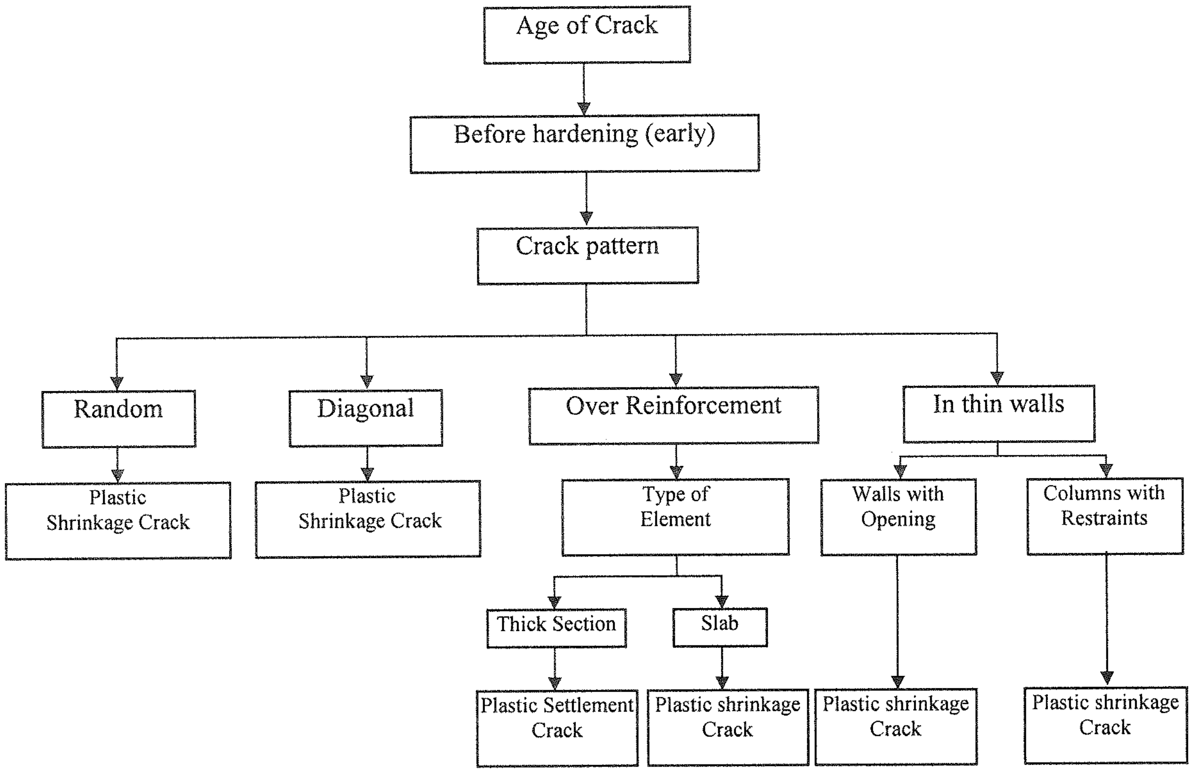


Figure (2) An example of a rule based hierarchical knowledge structure.

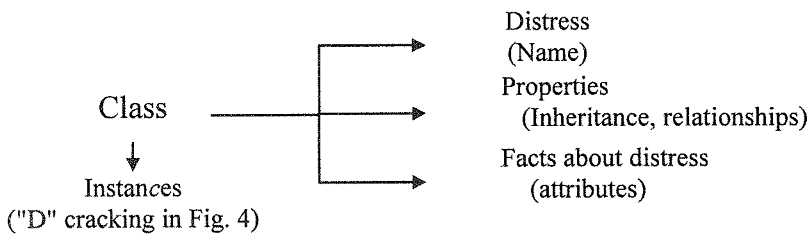


Figure (3) Example of an object-oriented knowledge structure.

3-Problem Definition

Concrete is a mixture of fine aggregate, coarse aggregate, water, and a type of cementation material such as Portland cement. This mixture has been usually used with steel rebar to developed to perform many types of intelligence tasks, and expectations are high for near term development of even more impressive system. There are two major traits of an expert we attempt to model in our system: the expert knowledge and reasoning. To accomplish this, the system must have two principal models: a knowledge base and an inference engine. This simple view of an expert system is illustrated in Figure 1 [13].

The knowledge base contains highly specialized knowledge on the problem area as provided by the experts. It includes problem facts, rules, concepts, and relationships. The inference engine is the knowledge processor witch is modeled after the expert's reasoning. The engine works with available information on a given problem, coupled with the knowledge stored in the knowledge base to draw conclusions or recommendations [13].

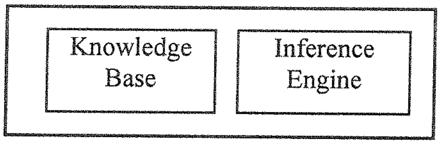


Figure (1) Expert system block diagram.

2-1-Rule Based Expert Systems

The majority of expert systems use the rule based method of representing knowledge. Rules are developed to tell the inference engine how to use the knowledge. Rules represent IF condition THEN action statements. For example:

If *the age of the concrete is before hardening,* ***And*** *the crack pattern is random,* **then** *the crack may be a plastic shrinkage crack.*

The inference engine uses a backward or forward chaining procedure to test for *true/false* conditions of a related sub-set of rules. This procedure is continued until an established goal *and/or* sub-goal is achieved. The goal may represent recommendations, conclusions, or a hypothesis. As mentioned above, there are two common method of inference technique: *backward chaining* and *forward chaining.*

The use of backward chaining inference implies that there is a single path (sub-set) of rules in attempting to find the goal. End-user inputs (answers to questions) are used to find the correct solution-set of rules. This is most common in diagnostic systems. In backward chaining inference, the system goals are stored in the knowledge base and it searches for the rules that can achieve it.

In the forward chaining inference procedure, there may be several solution-sets of rules possible in reaching the goal(s). The consequence of one rule being true may infer that another rule is true. Rules are chained in a forward direction, as the system attempts to search for new information in achieving the goal(s).

A powerful feature that exists in rule based expert systems is that inference mechanism allows the expert system designer to alter the true/false condition of the rules. This procedure deals with uncertainty of whether the rule is 100% true or false. For example, an operator response to a question may allow a range of certainty to be specified, (e.g. 70% sure of its accuracy). Figure 2 demonstrates an example of rule-based knowledge representation for the type of reinforced concrete cracks.

2-2-Object Oriented (Frame Based) Expert Systems

In an object-oriented expert system, knowledge is grouped in a such way that an expert normally thinks of the knowledge domain. The advantages of object-oriented expert systems are their ability to:

-Use multiple inference methods for a single knowledge base

In literature, there are several papers, research projects, and softwares in application of artificial intelligence (AI) and Expert System in civil engineering [3]. Elias reviews the possibilities of using AI techniques in design of aerospace structures [4]. Dixon and Simmons explore application of expert systems in mechanical design [5]. Finn reviews the application of expert system in construction engineering [6]. Adeli reviews some application of expert systems in construction and structural engineering [7]. Allen explore some methods of knowledge representation in civil engineering area [8]. Zhuo and Yangbiao develop an expert system (PADES) which is used to perform the shape optimum design of arch Dams [9]. Salvaneschi et al. use an rule-based expert system to safety monitoring and evaluation of structures especially in arch dams [10].

Table (I) Expert systems for concrete design, assessment and rehabilitation.

Expert System	Concrete Design Use	Condition Assessment	Repair	Rehabili tation	Prototype	Operational
BETVAL	■				■	
Bridge Rating Expert System		■			■	
COMIX	■				■	
CONCEX	■				■	
Concrete Mix Designer					■	
CRACK		■			■	
CRACKS		■			■	
DURCON	■				■	
ESCON	■				■	
EXPEAR		■	■	■		■
PAVEMENT EXPERT		■			■	
PAVER		■	■	■		■
REPCON		■			■	

The applications of expert systems in concrete design are not too much, compared to other engineering activities, such as traffic signal, transportation network design, etc. Table I lists the existing expert systems developed for concrete design, assessment and rehabilitation [11, 12].

This paper presents an expert system for diagnosis of deterioration of concrete structures. The rest of the paper is organized as follows: section 2 presents the essence of expert system. In section 3 the problem of deterioration of concrete structures is explained. Section 4 presents the problem solving approach to concrete structures. In section 5 system design and rule definition are investigated. Section 6 tests the proposed expert system. Finally, in section 7 the conclusions and future works are presented.

2-The Essence of An Expert System

Expert system is a branch of computer science concern with the studying and creating computer systems that exhibit some of intelligence: system that learns new concepts and tasks, system that can reason and draw useful conclusions about the world around us, system that can understand a natural language or perceive and comprehend a visual scene, and system that perform other types of feats that human types of intelligence [2, 13].

With the above definition, the question is that: are we able to build systems witch exhibit these characteristics? The answer to this question is yes! Systems have already been

Application of Expert Systems in Damage Assessment of Reinforced Concrete Structures

M. H. Fazel Zarandi*

J. Sobhani

Department of Industrial Engineering, Amirkabir University of Technology

Department of Civil and Environmental Engineering, Amirkabir University of Technology

Abstract

Expert systems are receiving great attentions in construction industry to support decision-making processes in diagnostics, design, repair and rehabilitation of the structures. Although several expert systems have been examined in engineering since the 1970's, their applications in construction industry are rare. This was largely due to the lack of expert system tools available to represent the domain knowledge. Lack of flexibility, applicability, and robustness of the classical models, have forced the scientists to discover the ability of the expert systems in problem solving of civil engineering. This paper presents an expert system for diagnosis the deterioration of concrete structures. This expert system emphasizes on cracking distress in reinforced concrete elements. A case study has been presented to examine and evaluate the proposed expert system. The system demonstrates a straightforward method for diagnosing the cause of reinforced concrete elements cracking

Keywords

Reinforced Concrete, Damage Assessment, Expert System, Rule-Based.

1-Introduction

For a long time, reinforced concrete has been a very common and widely used material for construction and buildings in civil engineering. Every body encounters reinforced concrete structures in her/his daily lives. Examples of these structures include highway bridges, pavements, retaining walls, piers and seawalls, drainage culverts, reservoirs, building blocks, and the like. It is of great concern to ensure that these reinforced concrete structures are safely maintained and be in a good working condition. The diagnosis of deterioration and other problems in reinforced concrete structures is of prime importance so that the condition of the reinforced concrete structures can be assessed and remedial actions can be taken before it is too late to do so. Chemical and physical processes such as sulfate and chloride attack, carbonation, and erosion are of important deterioration factors in reinforced concrete structures [1]. Every year, great amounts of budget are spent on repair and strengthening of damaged structures. Assessment and distinction of various types of damages in reinforced concrete structures is usually hard and needs to special expertise that are very expensive and usually inaccessible. Expert systems are suitable tools to resolve these kinds of problems in civil engineering. Recent development in knowledge based expert systems allow users to conveniently interrogate human like specialized computer programs. These expert systems together with their knowledge bases that are acquired from experts and their related search engines would behave as human experts. Recently, through these systems, many computer programs were written in the fields of engineering, medicine, psychology, economic, military, politic, and so on [2].