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Chapter 3.4.2.

Fuzzy Rule Based System for Diagnisis of Stone Construction Cracks of Buildings

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Key words: STONE CONSTRUCTION CRACK, DECICION MAKING, DIAGNOSIS, HIERARCHICAL FUZZY KNOWLEDGE BASES, TUNING.

Abstract: This paper presents a fuzzy expert system for intelligent support of decision making about cause of stone construction crack of building. The system is based on some linguistic expert expressions formalised by nine fuzzy knowledge bases. Tuning of fuzzy rules by genetic algorithms provided a good concordance between real causes of cracks and results of decision making by the system.

1. INTRODUCTION

Diagnosis (or determination of cause) of stone construction crack is an important task of building engineering. Instant and correct diagnosis of the stone construction cracks makes further investigations, design and reconstruction of buildings successful. The task of diagnosis may be solved correctly by high qualification engineers with large experience only. The number of such experts is lacking and in connection with this the design of intelligent system for crack of buildings diagnose is necessity.

This paper presents a fuzzy expert system for decision making support about the cause of stone construction crack of building. The approach to the system design suggested in this paper is based on:

– description of the structure of diagnostic model by hierarchical fuzzy logical evidence tree;
– presentation of state parameters in linguistic variable form;
– formalisation of linguistic terms by fuzzy sets;
– formalisation of expert nature language expressions about relationship «state parameters - diagnosis» by fuzzy knowledge bases;
– tuning of the knowledge bases by genetic optimization of membership functions parameters and weight of the rules.

The approach allows using as expert linguistic information as experimental data reflecting interconnection between input and output parameters. The use of all available source information provides increasing of diagnostic model quality.

2. PROBLEM STATEMENT

Different causes of stone construction cracks is classified by the followings diagnoses:

d_1 - static overload;
d_2 - dynamic overload;
d_3 - especial overload;
d_4 - defects of basis and foundation;
d_5 - temperature influence;
d_6 - breach of technological process of building.

Suggested classification accords to maximal depth of diagnosis, which can be got for case of visual investigations. Source information needed for decision making is data of visual investigation of building. These are values of the next factors (parameters of object state): x_1 - construction type; x_2 - work condition; x_3 - thickness of horizontal junctures; x_4 - defects of junctures filling; x_5 - defects of bandaging system; x_6 - unforeseen holes; x_7 - defects of reinforcing; x_8 - curve of construction; x_9 - deflection from vertical line; x_{10} - moistening of brickwork; x_{11} - peeling of brickwork; x_{12} - weathering of brickwork; x_{13} - leaching of brickwork; x_{14} - crumbling of brickwork; x_{15} - crack location; x_{16} - crack direction; x_{17} - opening of crack; x_{18} - crack width; x_{19} - crack length; x_{20} - consequences of fair; x_{21} - information about earthquakes, explosions; x_{22} - presence of dynamic load; x_{23} - splitting under straight; x_{24} - crack depth; x_{25} - displacement of breast-wall; x_{26} - damage of water-supply system; x_{27} - quality of drains; x_{28} - presence of loose soils; x_{29} - presence of water in cellar; x_{30} - presence of capacitevy construction close; x_{31} - presence of new adjacent buildings; x_{32} - displacement of straight, beam; x_{33} - necessity of sedimentary juncture; x_{34} - presence of sedimentary juncture; x_{35} - presence of additional loads; x_{36} - presence of mechanical damages; x_{37} - quality of cushions under beams; x_{38} - insufficient size of beans bearing place; x_{39} - necessity of temperature juncture; x_{40} - presence of temperature juncture; x_{41} - execution of works on winter; x_{42} - using of heterogeneous materials.

From a cybernetic point of view, creation of the diagnostic model for cause (D) of crack determination is reduced to finding out the representation of this form:

$$X = \{x_1,...,x_{42}\} \rightarrow D \in \{d_1,...,d_6\},$$

where X - a vector of the sate parameters.

3. FUZZY LOGICAL EVIDENCE TREE

Hierarchical interconnection between state parameters (X) and cause of crack (D) is represented by Figure 1 in the form of a fuzzy logical evidence tree. Graph vertices are interpreted in the following way (Rotshtein, 1998):

– the root - cause of crack;
– terminal vertices - partial state parameters;
– nonterminal vertices (double circles) - fuzzy knowledge bases.

Enlarged state parameters, to which graph edges correspond, as going out of nonterminal vertices are interpreted as followings:

y_1 - state of construction;
y_2 - destruction of brickwork;
y_3 - additional information;
y_4 - possibility of basis and foundation defects;
y_5 - possibility of static overload;
y_6 - demand to temperature juncture;
y_7 - possibility of crack connected with breach of technological processes;
y_8 - demand to sedimentary juncture.

The tie between state parameters and diagnosis is defined by this system of relations:

$$D = f_D(x_1, x_2, y_1, x_{15}, x_{16}, x_{17}, x_{18}, x_{19}, y_3);$$

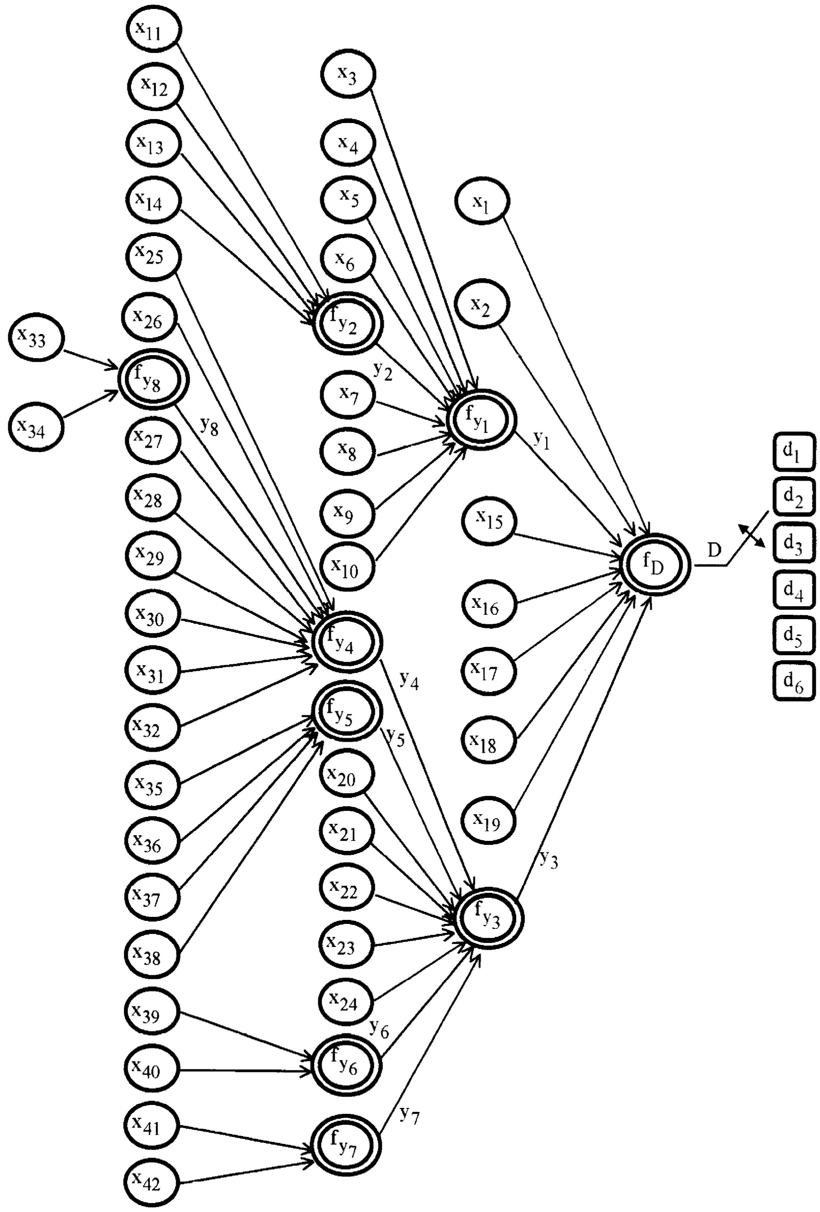

Figure 1. Fuzzy logical evidence tree

$$y_1 = f_{y_1}(x_3, x_4, x_5, x_6, y_2, x_7, x_8, x_9, x_{10});$$

$$y_2 = f_{y_2}(x_{11}, x_{12}, x_{13}, x_{14});$$

$$y_3 = f_{y_3}(y_1, y_5, x_{20}, x_{21}, x_{22}, x_{23}, x_{24}, y_6, y_7);$$

$$y_4 = f_{y_4}(x_{25}, x_{26}, y_8, x_{27}, x_{28}, x_{29}, x_{30}, x_{31}, x_{32});$$

$$y_5 = f_{y_5}(x_{35}, x_{36}, x_{37}, x_{38});$$

$$y_6 = f_{y_6}(x_{39}, x_{40});$$

$$y_7 = f_{y_7}(x_{41}, x_{42});$$

$$y_8 = f_{y_8}(x_{33}, x_{34}).$$

4. LINGUISTIC VARIABLES AND FUZZY KNOWLEDGE BASES

The state parameters are represented as linguistic variables (Zimmerman, 1996). The following 118 terms are used for linguistic assessment of partial state parameters:

x_1 - {deaf wall (DW), wall with pilaster (WP), pier (P), deaf partition (DP), pier with aperture (PA), wall with aperture (WA)};

x_2 - {holding (H), self-holding (SH) , non-holding (NH)};

x_3 - {normal (N), excessive (E), very excessive (VE)} ;

x_4 - {absence (A), some (S), many (M)};

x_5 - {absence (A), present (P)};
x_6 - {absence (A), present (P)};
x_7 - {absence (A), some (S), many (M)};
x_8 - {absence (A), present (P)};
x_9 - {absence (A), insignificant (I), considerable (C)};
x_{10} - {absence (A), insignificant (I), considerable (C)};
x_{11} - {absence (A), insignificant (I), considerable (C)};
x_{12} - {absence (A), insignificant (I), considerable (C)};
x_{13} - {absence (A), insignificant (I), considerable (C)};
x_{14} - {absence (A), insignificant (I), considerable (C)};
x_{15} - {across whole wall (AW), between walls (B), borders of wall (BW), from monolithic inclusion (MI), at supports (S), top of construction (TC), free field (FF), bottom of construction (BC)};
x_{16} - {vertical (V), oblique (O), horizontal (H)};
x_{17} - {up, slanting (S), down (D)};
x_{18} - {hair (H), small (S), average (A), large (L), very large (VL)};
x_{19} - {short (S), average (A), long (L), very long (VL)};
x_{20} - {absence (A), present (P)};
x_{21} - {absence (A), present (P)};
x_{22} - {absence (A), present (P)};
x_{23} - {absence (A), present (P)};
x_{24} - {one-sided (OS), through (T)};
x_{25} - {absence (A), present (P)};
x_{26} - {absence (A), present (P)};
x_{27} - {low (L), excellent (E)};
x_{28} - {absence (A), uncertainly (U), present (P)};
x_{29} - {absence (A), present (P)};
x_{30} - {absence (A), uncertainly (U), present (P)};
x_{31} - {absence (A), present (P)};
x_{32} - {absence (A), present (P)};
x_{33} - {unnecessary (UN), necessary (N)};
x_{34} - {absence (A), low quality (LQ), quality (Q)};
x_{35} - {absence (A), present (P)};
x_{36} - {absence (A), present (P)};
x_{37} - {low (L), high (H)};
x_{38} - {absence (A), present (P)};
x_{39} - {unnecessary (UN), necessary (N)};
x_{40} - {absence (A), low quality (LQ), quality (Q)};
x_{41} - {absence (A), uncertainly (U), present (P)};
x_{42} - {absence (A), uncertainly (U), present (P)}.

The following 24 terms are used for linguistic assessment of enlarged state parameters:

y_1 - {normal (N), weak (W), very weak (VW)};
y_2 - {absence (A), medium (M), heavy (H)};
y_3 - {absence (A), static overload (SO), dynamic overload (DO), especial overload (EO), defects of basis and foundation (BF), temperature influence (T), breach of technological process of building (TP)};
y_4 - {low (L), average (A), high (H)};
y_5 - {low (L), high (H)};
y_6 - {observed (O), ignored (I)};
y_7 - {low (L), high (H)};
y_8 - {observed (O), ignored (I)}.

Formalisation of linguistic terms are employed following membership function model (Rotshtein and Katelnikov, 1998):

$$\mu^t(x) = \frac{1}{1+\left(\frac{x-b}{c}\right)^2},$$

where $\mu^t(x)$ - membership function of variable x to term t;

b and c - tuning parameters - coordinate of maximum and concentration coefficient.

Natural language expert expressions, which tie up the state parameters and output variable, are formalised in fuzzy knowledge base form. Tables 1-9 show some fragments of fuzzy knowledge bases connected hierarchically. In the tables, the symbol "-" means relevant variable is excluded from a given rule. Total number of rules of all knowledge bases is 151.

Table 1. Fragment of fuzzy knowledge base about diagnoses

x_1	x_2	y_1	x_{15}	x_{16}	x_{17}	x_{18}	x_{19}	y_3	D
-	H	-	S	-	up	-	-	SO	d_1
WA	H	W	AW	O	S	H	VL	DO	d_2
DW	H	-	B	O	up	-	-	EO	d_3
WA	H	-	AW	V	up	L	VL	A	d_4
-	SH	W	B	V	up	H	-	A	d_4
DW	H	-	BC	V	D	L	-	BF	d_4
-	SH	N	TP	S	up	S	L	T	d_5
P	H	-	MI	S	up	H	A	TP	d_6

Table 2. Fragment of fuzzy knowledge base about parameter y_1

x_3	x_4	x_5	x_6	y_2	x_7	x_8	x_9	x_{10}	y_1
N	A	A	A	A	A	A	A	A	H
N	S	A	A	M	A	A	A	I	W
VE	-	P	P	-	-	-	-	-	VW

Table 3. Fragment of fuzzy knowledge base about parameter y_2

x_{11}	x_{12}	x_{13}	x_{14}	y_2
A	A	A	A	A
I	A	I	A	B
C	I	I	-	H

Table 4. Fragment of fuzzy knowledge base about parameter y_3

y_4	y_5	x_{20}	x_{21}	x_{22}	x_{23}	x_{24}	y_6	y_7	y_3
L	L	A	A	A	A	OS	O	L	A
-	H	-	-	-	-	-	-	-	SO
-	-	-	-	P	-	-	-	-	DO
-	-	-	P	-	-	-	-	-	EO
H	-	P	-	-	-	-	-	-	BF
-	-	-	-	-	-	-	I	-	T
-	-	-	-	-	-	-	-	H	TP

Table 5. Fragment of fuzzy knowledge base about parameter y_4

x_{25}	x_{26}	y_8	x_{27}	x_{28}	x_{29}	x_{30}	x_{31}	x_{32}	y_4
A	A	O	E	A	A	A	A	A	L
A	A	O	E	A	A	P	A	A	A
-	-	-	-	P	P	-	-	-	H

Table 6. Fragment of fuzzy knowledge base about parameter y_5

x_{35}	x_{36}	x_{37}	x_{38}	y_5
A	A	A	A	L
P	-	-	-	H
-	P	-	-	H

Table 7. Fragment of fuzzy knowledge base about parameter y_6

x_{39}	x_{40}	y_6
N	Q	O
UN	-	O
N	A	I

Table 8. Fragment of fuzzy knowledge base about parameter y_7

x_{41}	x_{42}	y_7
P	-	H
-	P	H
A	A	L

Table 9. Fragment of fuzzy knowledge base about parameter y_8

x_{33}	x_{34}	y_8
UN	-	O
N	A	I
N	LQ	I

A definite cause of crack will be determined by way of solving the system of fuzzy logical equations, which is isomorphic to hierarchical fuzzy knowledge base (Rotshtein, 1998). Fuzzy logical evidence is carried out according to the following algorithm (Rotshtein, 1998):

Step 1. Fix partial state parameters.

Step 2. Find partial state parameters membership degrees to linguistic terms.

Step 3. Weaken found membership degrees in fuzzy logic equations and calculate decision membership degrees to terms $d_1, d_2, \dots, d_6$.

Step 4. Choose the term from set $\{d_1, d_2, \dots, d_6\}$ with the maximum membership degree as the diagnosis.

Execution of step 2 according to (Rotshtein and Shtovba, 1998) allows to use as quantitative as qualitative values of state parameters.

5. SOFTWARE REALISATION AND CHECK EXAMPLE

The models and algorithms suggested here are realised in an expert system which provides intelligent support in decision making about cause of stone construction cracks of buildings. The system is realised on base of FuzzyExpert shell (Rotshtein, 1998).

An illustration of the proposed model and algorithm application is showed below. Let us consider the crack in wall of the Mogiliv-Podilsky Machine Works building. The next state parameters corresponding to the object: x_1 = deaf wall; x_2 = holding; x_3 = normal; x_4 = absence; x_5 = absence; x_6 = absence; x_7 = absence; x_8 = absence; x_9 = absence; x_{10} = absence; x_{11} = absence; x_{12} = absence; x_{13} = absence; x_{14} = = absence; x_{15} = between walls; x_{16} = vertical; x_{17} = up; x_{18} = 2 mm; x_{19} = 2 m; x_{20} = absence; x_{21} = absence; x_{22} = absence; x_{23} = present; x_{24} = through; x_{25} = absence; x_{26} = present; x_{27} = low; x_{28} = present; x_{29} = absence; x_{30} = available; x_{31} = absence; x_{32} = absence; x_{33} = unnecessary; x_{34} = absence; x_{35} = absence; x_{36} = absence; x_{37} = high; x_{38} = absence; x_{39} = unnecessary; x_{40} = absence; x_{41} = uncertainly; x_{42} = absence. As the results of the fuzzy logic evidence we obtain the following degrees of membership:

$$\mu^{d_1}(D) = 0.083; \quad \mu^{d_2}(D) = 0.01; \quad \mu^{d_3}(D) = 0.022;$$

$$\mu^{d_4}(D) = 1; \quad \mu^{d_5}(D) = 0.038; \quad \mu^{d_6}(D) = 0.027,$$

what correspond to solution d_4 - defects of basis and foundation.

6. TUNING OF FUZZY DECISION MAKING MODEL

Tuning (or parametrical identification) is the process of finding out such values of model parameters which provide least distance between results of modeling and experimental data. According to (Rotshtein and Katelnikov, 1998) the tuning parameters of fuzzy decision making model are membership functions parameters and weights of fuzzy rules. For our model the total number of this parameters is 2x(118+24)+151=435. The quantity of the tuning parameters is large, because of for solving this nonlinear large scale optimization task we employed genetic algorithms. Some examples of membership functions before and after optimization are showed on Figure 2.

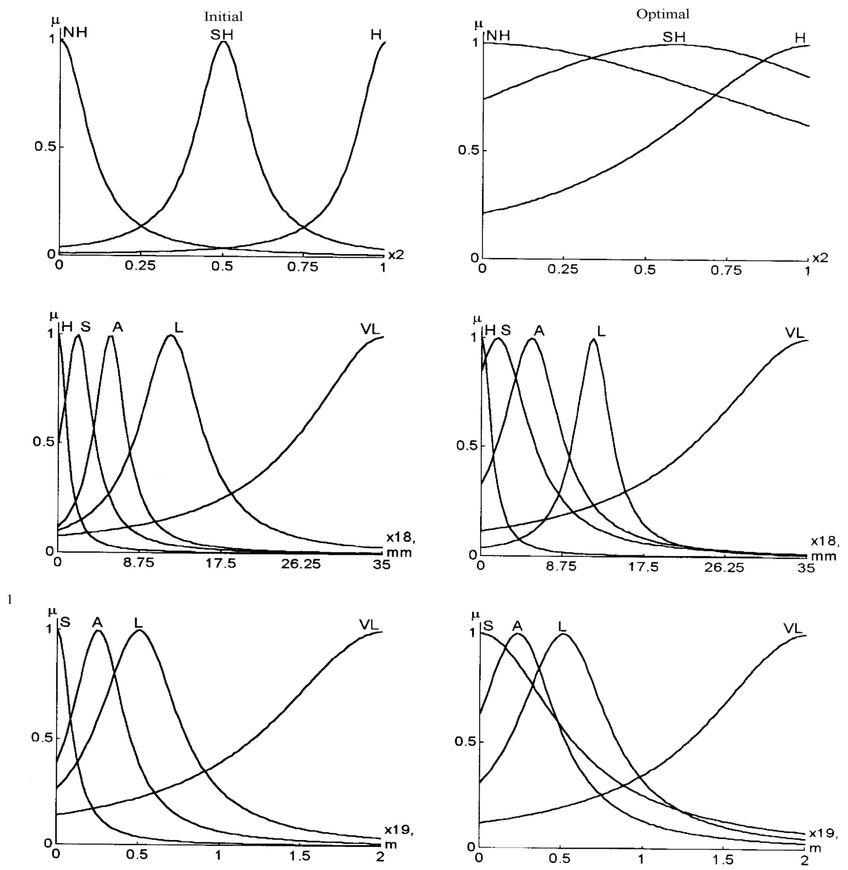

Figure 2. Examples of membership functions

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After tuning, the results of decision making by the system is a good concordant with real causes of cracks - the diagnostic error is about 4%. Values of diagnostic error for each type of decision are showed on Table 10.

Table 10. Experimental assessment of diagnostic errors

Type of decision	Quantity of objects	Quantity of error decisions
d_1	9	2
d_2	5	0
d_3	8	0
d_4	54	1
d_5	9	1
d_6	4	0
d_1-d_6	89	4

7. CONCLUSION

We have proposed a fuzzy expert system providing intelligent decision making support about cause of stone construction crack of buildings. The system can be use by professional building engineers and by engineering students. The design of our stone construction crack expert system suggests a general approach to expert systems design in other diagnostic fields.

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