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Assesment of existing reinforced concrete structures with usage of the fuzzy logic - based expert system

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Abstract

Fuzzy logic is a useful tool when assessing the existing reinforced concrete structures. The introduction of expert system in assessing the technical condition of the existing structures built on the fuzzy logic represents a transition to a new and higher-quality level for the survey of constructions sites. As a result, it is seen that the assessment of the existing building with the usage of the proposed expert system complies with the estimation of the qualified experts.

Keywords: expert system, fuzzy logic, existing structures.

1 Introduction

As it was shown in [7] the diagnostic process for evaluation of the safety level of existing buildings is based on a decisional tree in which the data information collected at each phase are processed and interpreted to define the successive step of the procedure. Following [7], in general case the estimation procedure consists of three main phases, which can be singled out as follow:
Phase A: Preliminary analysis (visual inspection; basic in-situ testing) aimed at obtaining a coarse estimation of the real conditions of the structure and defining a rapid mapping of instabilities, damage and vulnerability. Based on the data obtained, it will be then decided if further and more detailed investigation needs.
Phase B: Detailed in-depth investigation, including a complete and systematic survey of the degradation scenery; experimental and laboratory tests, including both destructive and non-destructive in-situ methods.
Phase C: Interpretation and assessment of the obtained results; formulation of the judgement on the level of damage and reliability; specification of the repair and retrofitting interventions need to meet safety format requirements.
Visual inspection becomes the ruling practice in the management of maintenance, even when the number and importance of the construction are significant. The process of evaluation of degradation based on the results of visual inspection is heavily affected by subjectivity. Most of the assessment approaches are similar in principle but vary in the details. To use the visual inspection as a robust and reliable instrument to evaluate the safety level of construction it was decided to take advantage of the ability of Fuzzy Logic to treat uncertainty as expressed by linguistic judgements [3, 11]. To create the multilevel expert system for existing structures assessment based on the diagnostic process outlined above, a Fuzzy Logic-based algorithm is proposed, which exploits the Fuzzy Logic Toolbox package of MatLabSoftware [7]. In this context, the Fuzzy Logic appears the most qualified tool for the processing of numerical data and uncertain information to obtain a linguistic description of structural damage.

2 Fuzzy Logic System: Development Steps

Figure 1. presents a general view of a fuzzy logic system that is widely used for the assessment of the different technical problems. A fuzzy logic system maps crisp inputs into crisp outputs. It contains four basic components: (1) fuzzifier; (2) rules; (3) inference engine and (4) defuzzifier. Once the rules have been established, a fuzzy logic system can be viewed as a mapping from inputs to outputs [1, 4]. The theoretical background of the Fuzzy Logic approach is described in detail in numerous publications [1, 6, 7, 9, 10].

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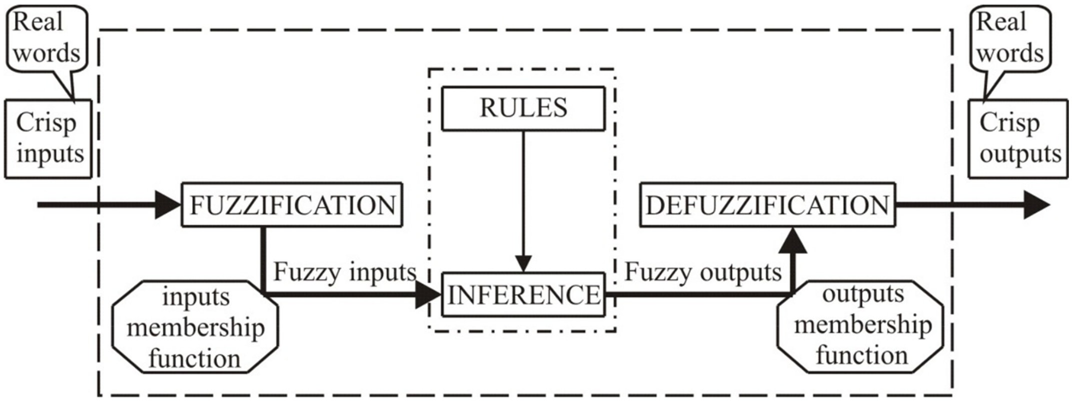

Figure 1. Block diagram of the fuzzy logic system [5]

Following [4] the expert system designed and developed depending on the experience and expertise of experts. The procedures for developing the proposed system are dividedinto two main steps: (1)designing and (2) implementation. For each there is a list of procedures as follows: -Designing: (a) Selecting Assessment Criteria; (b) Estimating the Importance of Assessment Criteria; (c) Designing of Damage Assessment Expert System. -Implementation: (a) Investigation and Inspecting; (b) Input Data; (c) Assessing the Structural State of the Building. As it was shown in [5] in the practical evaluation, one finds that the influence of the most basic variables is not as important as predicted. For instance, one originally regards that the deflection and strength of each member will result in decreased safety in the existing structure. Strength is generally satisfied by the specification requirements in the design. Therefore, to simplify the evaluation process, some variables, such as strength and so on are neglected in the evaluation method. In the proposed expert system, the basic variables are listed in Table 1. Based on classification and ranges of parameters for the basic variables stated in own studies, the relationship between the evaluation of basic variables in existing structures was established.

3 Rule-Based Fuzzy Model/Expert System Development

For the development of the fuzzy production model for assessing of the performance of the existing structure, it is necessary to formulate the following set , $X = \{x_i\}, i = \overline{1, n,}$ consisting the basic variables (see Table 1.) which are characterized performance of element and set $Y = \{y_j\}, j = \overline{1, m,}$, characterizing damage level (see Table 2.).

As it was shown above, in the damage assessment of an existing buildings (structures), several input data are required (crack width and propagation, residual strength of materials, amount and condition of the steel reinforcement,deflection, corrosion level et al.) that will all be treated, according to previous remarks, as fuzzy sets. The common structure deficiencies associated with the deterioration of the structural element are corrosion of steel reinforcement and the cracking, scaling and spalling concrete, deflections. The ranges for basic variables and correlation function were adopted based on their own numerical and experimental studies [7].

This is now to need to combine these elements each with the other, to obtain the desired final diagnosis of the existing structures. This performed by introducing proper «fuzzy rules», relating the above mentioned input data (resulting from direct and indirect inspections, testing,etc.) with the final output variable «damage», that is once again an element belonging to a fuzzy set (for example: «small damage», «moderate damage», «severe damage», see Figure 2.).

This means that the management of the problem is slightly more complex: to formulate a diagnosis, for each input variables (cracks amplitude, bars covering, etc.) membership functions are needed, and they have to be related to the output variable, expressing the damage level. The architecture of the proposed Fuzzy production model/expert system for assessing the existing structural members is shown in Figure 3.

Table 1. Input linguistic basic variables

Designation linguistic variables	Description of the linguistic variables	Term-set
Phase A: Visual Inspection (A-1)		
x_1	Crack propagation (bending/shear)	T4 = { no «0»; single «S»; numerous «N»; massive «M» }
x_2	Positions of the cracks (bending/shear)	T4 = { no «0»; in the mid-span «1»; near support «2»; mid-span+ near support «3» }
x_3	The longitudinal corrosion cracks propagation	T4 = { no «0»; local «L»; partial «P»; solid «S» }
x_4	Corrosion damage (deteriorations)	T2 = { no «0»; yes «1» }
x_5	Surface degradation of concrete (deteriorations)	T2 = { no «0»; yes «1» }
x_6	Propagation of the longitudinal corrosion cracks in compression zone of the section	T2 = {no «0»; yes «1» }
Phase A: Basic Testing (A-2)		
x_7	Concrete cover to diameter ratio, $\frac{c}{\phi}$	T3 = {small «S»; mean «M»; large «L» }
x_8	Load-induced cracks width, w_k (bending/shear)	T4 = {small «S»; permissible «P»; exceeded «E»; excessive «Ex» }
x_9	Longitudinal corrosion cracks width, w_I	T3 = {small «S»; medium «M»; excessive «E» }
x_{10}	Level of the reinforcement corrosion	T3 = {small «S»; mean «M»; large «L» }
x_{11}	Deflection ratio, $\frac{\delta}{L}$	T4 = {small «S»; permissible «P»; exceeded «E»; excessive «Ex» }
Phase A: Damage Class		
x_{12}	Visual Inspection (A-1)	T3 = {critical «1»; significant «2»; minor «3» }
x_{13}	Basic Testing (A-2)	T3 = {critical «1»; significant «2»; minor «3»}
x_{14}	Documentation	T2 = { no «0»; yes «1» }

3.1 Realization of the Fuzzy production model for assessment of existing structures in MatLab Software

Step 1: Fuzzification – Input Fuzzy. At this stage, the membership function is adopted for term-sets of input and output linguistic variables, as shown in Table 3. The most commonly used membership functions are the trapezoidal and triangular one, that will be indeed the functions adopted in the proposed algorithm.

Step 2: Setting Fuzzy Rules in accordance with Table 4. The base of the Rules of the Fuzzy production model

Table 2. Output linguistic basic variables

Designation linguistic variables	Description of the linguistic variables	Term-set
y_1	Damage level	T3= { critical «1»; significant «2»; minor «3» }
y_2	Damage level	T3= {critical «1»; significant «2»; minor «3» }
y_3	Damage class	T3= { small «1»; moderate «2»; severe «3» }

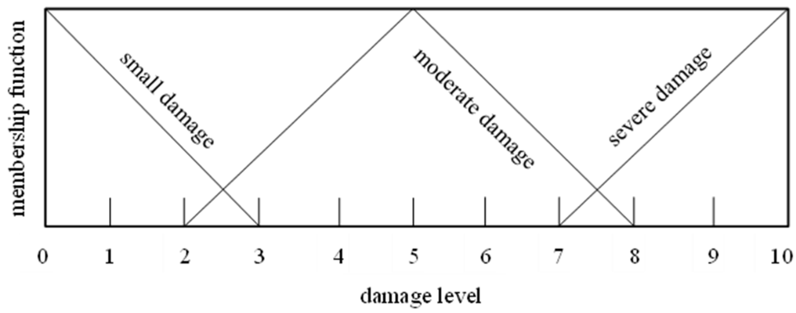

Figure 2. Triangular membership function for the output variable «damage»

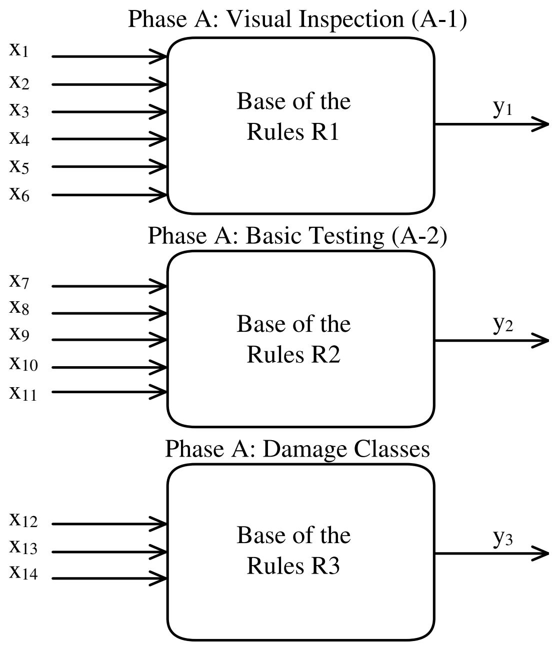

Figure 3. The structure of the proposed Rule-Based Fuzzy Model

is defined as a structure with an appropriate member of inputs x_i and one output y_i (see Figure 4.) in accordance with the logic relationships.

Step 3: Aggregation is the process by which the fuzzy set that represents the outputs of each rule are combined into a single fuzzy set. A rule premise, in general, is a compound fuzzy proposition. Aggregation only occurs once for each output variable, which is before the final defuzzification step. According to the original proposal of Zadeh for aggregation of the confidence level of assumption min-conjunction is used:

$$\alpha_i = min\left\{\mu_{A_{i1}}(x_1), \mu_{A_{i2}}(x2), \mu_{A_{i3}}(x3), \mu_{A_{i4}}(x4)\right\}, i = 1, 2, ..., n \tag{1}$$

Step 4: Activation. A fuzzy «IF-THEN» rule is a connection of two (compound) fuzzy propositions. Hence, this

Table 3. Membership functions mathematical descriptions

Designation of the linguistic variables	Membership function type	Mathematical description (upper index designate the corresponding term)
x_1	Trapezoidal	$\mu_\Delta{}^0$ (x; -1; -1; 0; 0), $\mu_\Delta{}^S$ (x; 0.5; 0.5; 5; 15), $\mu_\Delta{}^N$ (x; 5; 15; 35; 45), $\mu_\Delta{}^M$ (x; 35; 45; 90; 100)
x_2	Triangular	$\mu_\Delta{}^0$ (x; -0.5; 0; 0.5), $\mu_\Delta{}^1$ (x; 0.5; 1; 1.5), $\mu_\Delta{}^2$ (x; 1.5; 2; 2.5), $\mu_\Delta{}^3$ (x; 2.5; 3; 3.5)
x_3	Trapezoidal	$\mu_\Delta{}^0$ (x; -1; -1; 0; 0),$\mu_\Delta{}^L$ (x; 0.5; 0.5; 5; 15),$\mu_\Delta{}^E$ (x; 5; 15; 35; 45), $\mu_\Delta{}^{Ex}$ (x; 35; 45; 90; 100)
x_4	Triangular	$\mu_\Delta{}^0$ (x; -0.5; 0; 0.5), $\mu_\Delta{}^1$ (x; 0.5; 1; 1.5)
x_5	Triangular	$\mu_\Delta{}^0$, (x; -0.5; 0; 0.5), $\mu_\Delta{}^1$ (x; 0.5; 1; 1.5)
x_6	Triangular	$\mu_\Delta{}^0$, (x; -0.5; 0; 0.5), $\mu_\Delta{}^1$ (x; 0.5; 1; 1.5)
x_7	Trapezoidal	$\mu_\Delta{}^S$,(x; -1; 0; 0.5; 1.5), $\mu_\Delta{}^M$ (x; 0.5; 1.5; 2.5; 3.5), $\mu_\Delta{}^S$ (x; 2.5; 3.5; 8; 10)
x_8	Trapezoidal	$\mu_\Delta{}^S$, (x; -0.1; 0; 0; 0.1), $\mu_\Delta{}^P$ (x; 0; 0.1; 0.35; 0.45), $\mu_\Delta{}^E$ (x; 0.35; 0.45; 0.95; 1.05), $\mu_\Delta{}^{Ex}$ (x; 0.95; 1.05; 1.2; 2)
x_9	Trapezoidal	$\mu_\Delta{}^S$ (x; -0.1; 0; 0; 0.1), $\mu_\Delta{}^M$(x; 0; 0.1; 0.95; 1.05), $\mu_\Delta{}^E$ (x; 0.95; 1.05; 2; 3)
x_{10}	Trapezoidal	$\mu_\Delta{}^S$ (x; -1.5; 0; 0.5; 1.5), $\mu_\Delta{}^M$ (x; 0.5; 1.5; 2.5; 3.5), $\mu_\Delta{}^L$ (x; 2.5; 3.5; 5; 8)
x_{11}	Trapezoidal	$\mu_\Delta{}^S$ (x; -0.001; 0; 0,0005; 0.0015), $\mu_\Delta{}^P$ (x; 0.0005; 0.0015; 0.0035; 0.0045), $\mu_\Delta{}^E$ (x; 0.0035; 0.0045; 0.0195; 0.0205), $\mu_\Delta{}^{Ex}$ (x; 0.0195; 0.0205; 0.025; 0.03)
x_{12}	Triangular	$\mu_\Delta{}^1$ (x; 0.5; 1; 1.5), $\mu_\Delta{}^2$ (x; 1.5; 2; 2.5), $\mu_\Delta{}^3$ (x; 2.5; 3; 3.5)
x_{13}	Triangular	$\mu_\Delta{}^1$ (x; 0.5; 1; 1.5), $\mu_\Delta{}^2$ (x; 1.5; 2; 2.5), $\mu_\Delta{}^3$ (x; 2.5; 3; 3.5)
x_{14}	Triangular	$\mu_\Delta{}^0$ (x; -0.5; 0; 0.5), $\mu_\Delta{}^1$ (x; 0.5; 1; 1.5)
y_1	Triangular	$\mu_\Delta{}^1$ (x; 0.5; 1; 1.5), $\mu_\Delta{}^2$ (x; 1.5; 2; 2.5), $\mu_\Delta{}^3$ (x; 2.5; 3; 3.5)
y_2	Triangular	$\mu_\Delta{}^1$ (x; 0.5; 1; 1.5), $\mu_\Delta{}^2$ (x; 1.5; 2; 2.5), $\mu_\Delta{}^3$ (x; 2.5; 3; 3.5)
y_3	Triangular	$\mu_\Delta{}^1$ (x; 0.5; 1; 1.5), $\mu_\Delta{}^2$ (x; 1.5; 2; 2.5), $\mu_\Delta{}^3$ (x; 2.5; 3; 3.5)

connective has to be interpreted within the framework of set-theoretic or logical operators. The simplest interpretation is that of the conjunction of premise and conclusion, such that the appropriate operation is the minimum:

$$\mu_{B_i}(y) = min\left\{\alpha_i, \mu_{B_i}(y)\right\}, i = 1, 2, ...n \tag{2}$$

Step 5: Accumulation. Usually, a rule base is interpreted as a disjunction of rules, i.e. rules are seen as independent «experts». Accumulation has the task to combine the individual «expert statements», which are fuzzy sets of recommended output values. Consequently, an appropriate accumulation operation is the maximum:

$$\mu_{B'}(y) = max\left\{\mu_{B_i}(y), \mu_{B'_2}(y), ..., \mu_{B'_n}(y)\right\} \tag{3}$$

Step 6: Defuzzification– from a fuzzy decision to real decision. As inference results in a fuzzy set, the task of defuzzification is to find the numerical value which «best» comprehends the information contained in this fuzzy

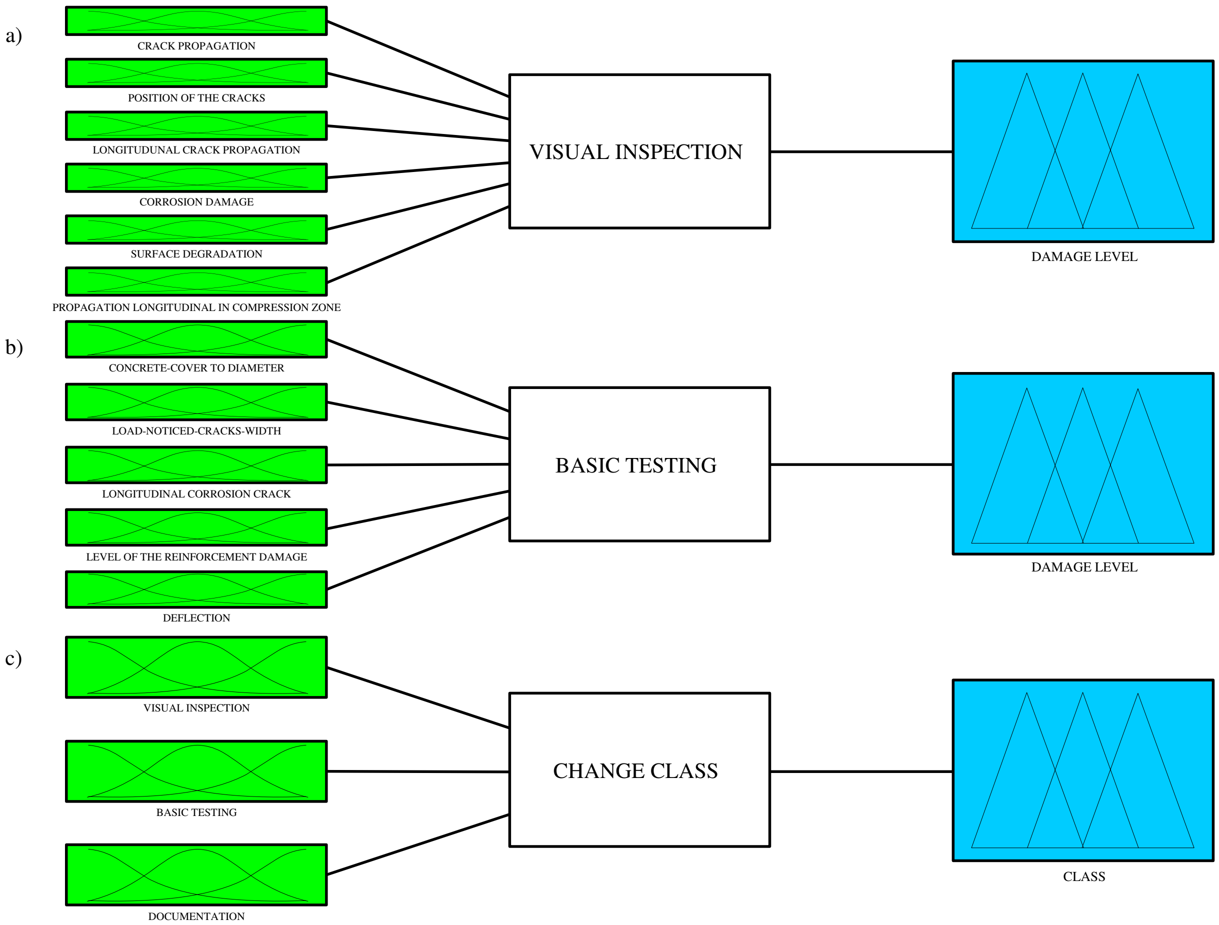

Figure 4. The «black boxes» for the Visual Inspection (a), the Basic Testing (b), the Damage Class or Phase A (c)

Table 4. Example of the Fuzzy Rules of the production model

Rule number	Antecedent	Consequent
	The base of the rules R1	
R1.1	$(x_1=0\wedge\ x_2=0\ \wedge\ x_3=0\wedge\ x_4=0\wedge\ x_5=1\wedge\ x_6=\ 0)\vee$ $(x_1=0\wedge\ x_2=0\ \wedge\ x_3=0\wedge\ x_4=1\wedge\ x_5=1\wedge\ x_6=\ 0)\vee$ $(x_1=E\wedge\ x_2=1\ \wedge\ x_3=0\wedge\ x_4=0\wedge\ x_5=0\wedge\ x_6=\ 0)\vee$ $(x_1=E\wedge\ x_2=2\ \wedge\ x_3=0\wedge\ x_4=0\wedge\ x_5=0\wedge\ x_6=\ 0)\vee$ $(x_1=E\wedge\ x_2=1\ \wedge\ x_3=0\wedge\ x_4=0\wedge\ x_5=1\wedge\ x_6=\ 0)\vee$ $(x_1=E\wedge\ x_2=2\ \wedge\ x_3=0\wedge\ x_4=0\wedge\ x_5=1\wedge\ x_6=\ 0)\vee$ $(x_1=E\wedge\ x_2=3\ \wedge\ x_3=0\wedge\ x_4=0\wedge\ x_5=1\wedge\ x_6=\ 0)\vee$ $(x_1=E\wedge\ x_2=3\ \wedge\ x_3=0\wedge\ x_4=0\wedge\ x_5=1\wedge\ x_6=\ 0)$	$y_1=3$
<...>		
R3.3	$(x_{12}\ =\ 2\wedge\ x_{13}=1\wedge x_{\ 14}\ =0\ )\vee$ $(x_{12}\ =\ 1\wedge\ x_{13}=2\wedge x_{\ 14}\ =0\ )\vee$ $(x_{12}\ =\ 1\wedge\ x_{13}=1\wedge x_{\ 14}\ =1\ )\vee$ $(x_{12}\ =\ 1\wedge\ x_{13}=1\wedge x_{\ 14}\ =0\ )$	$y_3=3$

set. A frequently used method is the so-called Center-of-Gravity defuzzification (CoG, also called Center-of-Area defuzzification CoA):

$$y' = \frac{\int_{y_{min}}^{y_{max}} y\mu_{B'}(y)dy}{\int_{y_{min}}^{y_{max}} \mu_{B'}(y)dy} \quad (4)$$

which chooses the y′ – coordinate of the centre of gravity of the area below the graph μ(y). This defuzzification can be interpreted as a weighted mean, i.e. each value y weighted with μ(y) and integral in the denominator serves for normalization.

3.2 Implementation of the Assessment Algorithm of the Proposed Expert System

According to [7] the whole phase is managed by a nested fuzzy algorithm: starting from the assessment of the single structural elements, and progressively proceeding through the structural hierarchy (element/storey/building), input data are processed and collated in order to obtain the new Phase – assessment of the whole building. It is worth remarking that part of the results provided by the preliminary investigation could be used also at this stage.

The starting point, as it has pointed out in numerous publications [2, 8], is the availability of an inventory of data and information derived from the investigation on the analyzed building, the collecting and organization of which is performed by using the survey diagnostic forms, as it is shown in Table 5-10.

The form (see Table 5-10) to be used in Phase A of Diagnostic Protocol should trivially contain all the fields required as an input by the algorithm, organized in such a way to permit the correct implementation of the software.

For each of the diagnostic phases (see Table 5-10), a set of sequential operation is performed: at each step data are recorded in the program, fuzzified and then processed to obtain an intermediate output. At the end of the chain, the combination of the partial results provides the safety assessment, in the form of qualitative judgement, together with a numerical score.

According to the protocol outlined above (see Table 5-10), the fuzzy algorithm manages the assessment of the damage, in general, in two consecutive phases: Preliminary Investigation – Phase A and In-depth Investigation – Phase B. For each of them, a properly chosen set of data and information is collected and processed for the formulation of the synthetic final assessment.

In Figure 4., the scheme of the two «black boxes» is shown: the input data, represented by scores of the individual observations and testing, are processed through the fuzzy rules, providing the value of the damage. At this point, the judgment of the Visual Inspection and Basic Testing are combined with results derived from the evaluation of the general features of the structure (as it was shown in [7], this step is performed with no fuzzification).

The diagnosis about building, concerning the Phase A is eventually obtained from these three (two) partial scores (see Figure 4.) and is once again expressed with a coefficient varying in the interval 1-10 according to [7].

4 Conclusions

1. An effective structural assessment expert system for evaluation of the existing reinforced concrete structural systems using Fuzzy Logic MatLab Toolbox was developed and verified on the real objects in this study.

2. Although the presented expert system based on close visual inspections and simple measurements, it may provide substantial assistance to more complicated work (for example, evaluation of existing structures based on detailed investigations).

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Table 5. The Diagnostic Protocol Form

<table>
<tr><td colspan="5">Phase A: Visual Inspection (A-1)</td></tr>
<tr><td>Structural Member</td><td colspan="4"></td></tr>
<tr><td>General Description</td><td colspan="4"></td></tr>
<tr><td rowspan="3">Propagation of the flexural (bending)/shear cracks, x_1</td><td colspan="4">Parameter: propagation length of the damaged linear size, [%] span length</td></tr>
<tr><td>no</td><td>single</td><td>numerous</td><td>massive</td></tr>
<tr><td>0</td><td>0.5-10</td><td>10-40</td><td>>40</td></tr>
<tr><td>Inspection results</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">Position of the flexural (bending)/shear cracks, x_2</td><td colspan="4">Parameter: position in a span</td></tr>
<tr><td>no</td><td>mid-span</td><td>near support</td><td>mid-span+near support</td></tr>
<tr><td>0</td><td>1</td><td>2</td><td>3</td></tr>
<tr><td>Inspection results</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">Propagation of the longitudinal corrosion cracks, x_3</td><td colspan="4">Parameter: propagation length,[%] span length</td></tr>
<tr><td>no</td><td>local</td><td>partial</td><td>solid</td></tr>
<tr><td>0</td><td>0.5-10</td><td>10-40</td><td>>40</td></tr>
<tr><td>Inspection results</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">Corrosion damage (deterioration), x_4</td><td colspan="4">Parameter: damage appearance</td></tr>
<tr><td colspan="2">no</td><td colspan="2">yes</td></tr>
<tr><td colspan="2">0</td><td colspan="2">1</td></tr>
<tr><td>Inspection results</td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td rowspan="3">Corrosion damage (deterioration), x_5</td><td colspan="4">Parameter: damage appearance</td></tr>
<tr><td colspan="2">no</td><td colspan="2">yes</td></tr>
<tr><td colspan="2">0</td><td colspan="2">1</td></tr>
<tr><td>Inspection results</td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td rowspan="3">Propagation of the longitudinal corrosion cracks in the compression zone of the section, x_6</td><td colspan="4">Parameter: damage</td></tr>
<tr><td colspan="2">no</td><td colspan="2">yes</td></tr>
<tr><td colspan="2">0</td><td colspan="2">1</td></tr>
<tr><td>Inspection results</td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>Damage Level</td><td colspan="4"></td></tr>
</table>

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Table 6. The Diagnostic Protocol Form

Phase A: Basic Testing (A-2)			
Characteristic of the Structure	Parameters		
Concrete			
Ratio c/ϕ (concrete cover/diameter), x_7	Parameter: c/ϕ		
	small	mean	large
	<1	1-3	>3
Inspection results			
Damage Level			

Table 7. The Diagnostic Protocol Form

Phase A: Basic Testing (A-2)				
Characteristic of the Structure	Parameters			
Concrete				
Flexural (bending) cracks, x_8	Parameter: crack width, w_k			
	small	permissible	exceeded	excessive
	no more 0.05 mm	from 0.05 to 0.4 mm	from 0.4 to 1 mm	more 1 mm
Inspection results				
Damage Level				

Table 8. The Diagnostic Protocol Form

Phase A: Basic Testing (A-2)			
Characteristic of the Structure	Parameters		
Concrete			
Longitudinal corrosion crack, x_9	Parameter: corrosion crack width, w_l		
	small	medium	large
	no more 0.05 mm	from 0.05 to 1 mm	more 1 mm
Inspection results			
Damage Level			

Table 9. The Diagnostic Protocol Form

<table>
<tr><td colspan="4">Phase A: Basic Testing (A-2)</td></tr>
<tr><td>Characteristic of the Structure</td><td colspan="3">Parameters</td></tr>
<tr><td colspan="4">Concrete</td></tr>
<tr><td rowspan="3">Level of the corrosion damage, $x_1 0$</td><td colspan="3">Reinforcement (steel)</td></tr>
<tr><td>small</td><td>mean</td><td>large</td></tr>
<tr><td>no more 1 %</td><td>from 1 to 3 %</td><td>more 3%</td></tr>
<tr><td>Inspection results</td><td></td><td></td><td></td></tr>
<tr><td>Damage Level</td><td colspan="3"></td></tr>
</table>

Table 10. The Diagnostic Protocol Form

<table>
<tr><td colspan="5">Phase A: Basic Testing (A-2)</td></tr>
<tr><td>Characteristic of the Structure</td><td colspan="4">Parameters</td></tr>
<tr><td colspan="5">Concrete</td></tr>
<tr><td rowspan="3">Deflections, $x_1 1$</td><td colspan="4">Deflections, deformations</td></tr>
<tr><td>small</td><td>permissible</td><td>exceeded</td><td>excessive</td></tr>
<tr><td>no more 1/900</td><td>from 1/900 to 1/250</td><td>from 1/250 to 1/50</td><td>more 1/50</td></tr>
<tr><td>Inspection results</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">Documentation</td><td colspan="2">no</td><td colspan="2">yes</td></tr>
<tr><td colspan="2">0</td><td colspan="2">1</td></tr>
<tr><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>Damage Class</td><td colspan="4"></td></tr>
<tr><td colspan="5">Notes: Surface degradations of the concrete characterizes by changing of the colour, oiling the surface of concrete, peeling, chipping, abrasion of surface, damage caused by freezing-thawing, etc</td></tr>
</table>