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Proposal for an Inspection Tool for Damaged Structures after Disasters

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Abstract: This study focuses on the development of a multifunctional Expert System (ES) called post-seismic damage inspection tool (PSDIT), a powerful tool which allows the evaluation, the processing and the archiving of the collected data stock after earthquakes. PSDIT can be operated by two user types; an ordinary user (engineer, expert or architect) for the damage visual inspection and an administrative user for updating the knowledge and / or for adding or removing the ordinary user. The knowledge acquisition is driven by a hierarchical knowledge model, the Information from investigation reports, and those acquired through feedback from expert / engineer questionnaires are part**.**

Keywords: Disaster, Damaged structures, Damage assessment, Expert system.

Introduction

In Algeria the post-seismic survey is usually conducted by simplified approaches, based on the evaluation form. This form is the result of field experience, refined after several successive earthquakes. Indeed, the visual inspections as well as the evaluations are established with a common and standard language for the damages description. However, the experience gained during the various earthquakes (in particular the Boumerdes earthquake, Algeria, 21 May 2003) shows that several problems may arise during this damage assessment phase. Among these problems, we distinguish on the one hand, those related to the subjectivity of some results due to non-compliant inspections (Anagnostopoulos & Moretti, 2008) and on other hand, those related to the short time allowed for the inspection process due the need for the occupants to return their homes shortly after the occurrence of the earthquake (Allali, 2018). To remedy these imperfections, the only solution is to bring improvements to the inspection tools. Moreover, in order to appreciate effectively the degradation state after an earthquake and reduce the risk, we have to design new more sophisticated inspection tools (Bosi et al., 2011; Baggio et al., 2007).

Several strategies have been adopted the field of damage detection; with high resolution imagery (Bechtoula & Ousalem, 2005; Saito, 2004). and artificial intelligence theory-based systems (Anagnostopoulos & Moretti, 2008; Akkouche et al., 2019; Boukri et al., 2013; Churilov, 2009). All these techniques represent an important technological advance in this field, and their applications represent a success with the post-event management managers. On the other hand, they have no interest in the general public immediate needs, which is of paramount importance for their life safety and for the post-event situation management. Indeed, the survivor's participation in the damage assessment can be, in this situation, of a precious help. In this paper, a knowledge-based expert system PSDIT for the structures diagnosis undergoing seismic damage is proposed. This approach insists to answer the omissions made by the organisms (CTC, CGS… etc.), PSDIT is developed using object-

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oriented programming tools. PSDIT data and knowledge are collected from different sources. The damage level estimation is based on mathematical models developed in the first part of the study (Akkouche et al., 2019).

Post-Seismic Damage Assessment

In Algeria, to evaluate post-seismic damage, an intuitive procedure based mainly on visual observation is used. This procedure consists of filling in the form given in Figure 1.

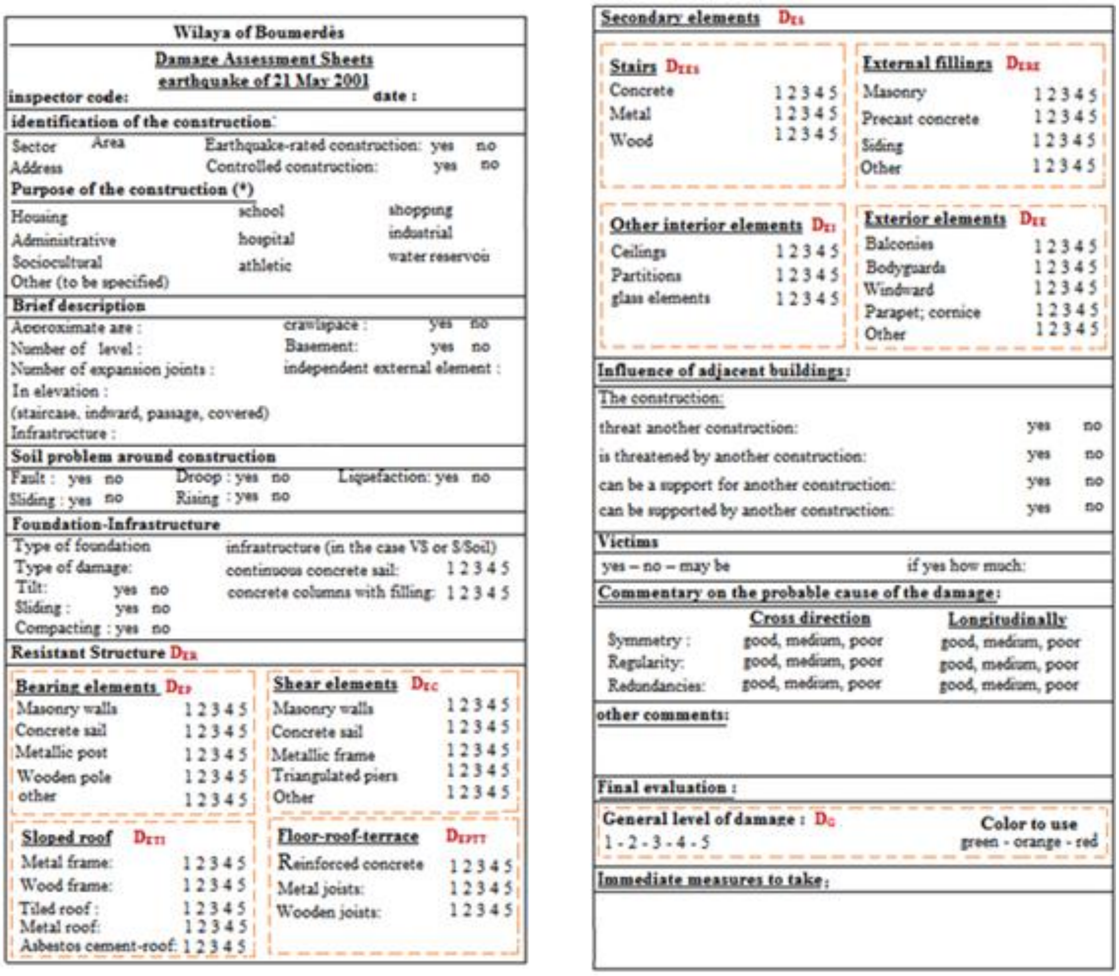
Wilaya of Boumerdès
Damage Assessment Sheets
earthquake of 21 May 2001
inspector code: date :
identification of the construction
Sector Area Earthquake-rated construction: yes no
Address Controlled construction: yes no
Purpose of the construction (*)
Housing school shopping
Administrative hospital industrial
Sociocultural athletic water reservoir
Other (to be specified)
Brief description
Approximate age : crawlspace : yes no
Number of level : Basement: yes no
Number of expansion joints : independent external element :
In elevation :
(staircase, indward, passage, covered)
Infrastructure :
Soil problem around construction
Fault : yes no Droop : yes no Liquefaction: yes no
Sliding : yes no Rising : yes no
Foundation-Infrastructure
Type of foundation infrastructure (in the case VS or S/Soil)
Type of damage: continuous concrete sail: 1 2 3 4 5
Tilt: yes no concrete columns with filling: 1 2 3 4 5
Sliding : yes no
Compacting : yes no
Resistant Structure D_{ER}
Bearing elements D_{EP}: Masonry walls 1 2 3 4 5; Concrete sail 1 2 3 4 5; Metallic post 1 2 3 4 5; Wooden pole 1 2 3 4 5; other 1 2 3 4 5
Shear elements D_{EC}: Masonry walls 1 2 3 4 5; Concrete sail 1 2 3 4 5; Metallic frame 1 2 3 4 5; Triangulated piers 1 2 3 4 5; Other 1 2 3 4 5
Sloped roof D_{ETI}: Metal frame: 1 2 3 4 5; Wood frame: 1 2 3 4 5; Tiled roof: 1 2 3 4 5; Metal roof: 1 2 3 4 5; Asbestos cement-roof: 1 2 3 4 5
Floor-roof-terrace D_{EPTT}: Reinforced concrete 1 2 3 4 5; Metal joists: 1 2 3 4 5; Wooden joists: 1 2 3 4 5
Secondary elements D_{ES}
Stairs D_{EES}: Concrete 1 2 3 4 5; Metal 1 2 3 4 5; Wood 1 2 3 4 5
External fillings D_{ERE}: Masonry 1 2 3 4 5; Precast concrete 1 2 3 4 5; Siding 1 2 3 4 5; Other 1 2 3 4 5
Other interior elements D_{EI}: Ceilings 1 2 3 4 5; Partitions 1 2 3 4 5; glass elements 1 2 3 4 5
Exterior elements D_{EE}: Balconies 1 2 3 4 5; Bodyguards 1 2 3 4 5; Windward 1 2 3 4 5; Parapet; cornice 1 2 3 4 5; Other 1 2 3 4 5
Influence of adjacent buildings:
The construction:
threat another construction: yes no
is threatened by another construction: yes no
can be a support for another construction: yes no
can be supported by another construction: yes no
Victims
yes – no – may be if yes how much:
Commentary on the probable cause of the damage:
Cross direction Longitudinally
Symmetry : good, medium, poor good, medium, poor
Regularity: good, medium, poor good, medium, poor
Redundancies: good, medium, poor good, medium, poor
other comments:
Final evaluation :
General level of damage : D_G 1 - 2 - 3 - 4 - 5 Color to use green - orange - red
Immediate measures to take:

Figure 1. The evaluation form used in Algeria (Akkouche et al., 2019).

This procedure considers a five-level damage scale (ranging from D1 to D5), similar to the damage scale given by EMS-98 (Grunthal & Levret, 2001)"Thus, concerning the assessment of the construction elements damage level (structural elements, non-structural elements and foundation system), it is done on five damage categories, varying from a slight damage (noted D1) to a high damage (noted D5). However, concerning the construction external elements (the construction ground, adjacent structures), these are evaluated by "Yes", in the case where the threat exists and "No" in the opposite case, which represent respectively the scale bounds (D1 and D5). Then, depending on the damage observed on the different components, a global damage category D_G will be attributed to the structure.

Architecture of the Proposed System

Our proposed system Expert System for assessment damage is a rule based ES which has been developed using JESS, the Java Expert System Shell. The user of the ES is first presented with a set of questionnaires to access the assessment damages. The questionnaires are presented in simple Frensh, which the user has to answer in affirmative or negative. According to the information provided by the user, the ES makes use of the RETE algorithm to match the pattern facts with the rules. Once a certain rule is matched, the rule is fired and according to the rules stored in the knowledge base, the user is presented with an assessment.

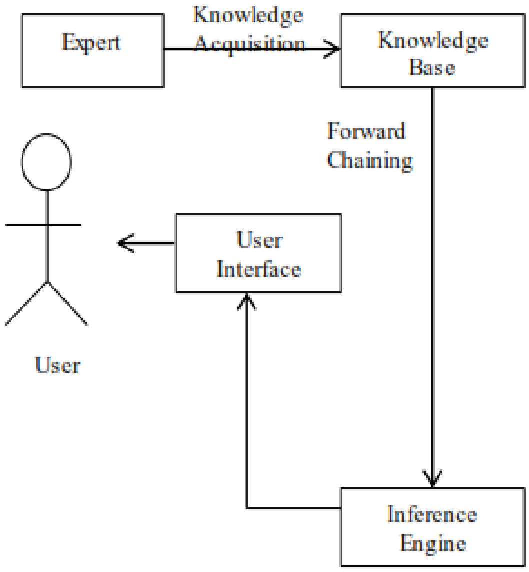

Figure 2. Architecture of the proposed system.

Knowledge Acquisition

The first and foremost work for building an Expert System is preparing a knowledge base for the system (Churilov, 2009). The primary source of information was interaction with experts and postgraduate students of the civil engineering department of the Mouloud MAMMERI University. The second source of acquisition of knowledge was from the internet.

Knowledge Representation

For knowledge representation, we used the JESS to represent facts and form the rules. First we present the questions before the user asking if the component has suffered from the damages mentioned in the scientific work (Akkouche et al., 2019). The user either puts his answer as yes or no. We also take a global counter for the purpose of storing our cumulative weight age score.

The RETE Algorithm

The RETE algorithm is the core of the Java Expert System Shell forsearching patterns in the rules. It is one of the most used algorithms for pattern searching. It highly speeds up the searching process by limiting the effort to recompute the conflicts after a rule is fired (Liao, 2005). The RETE algorithm is implemented as directed acyclic graphs which are used to match rules to facts (Grunthal & Levret, 2001).

Expert's Know-How

Knowledge is represented by the facts use and rules as modalities.

The Facts

The facts represent all the damage that may occur after a seismic event, such as; cracks, concrete bursting ... etc. In this study, they differ from one user to another. In the evaluation case by owner, a fact is represented by a question. That is, a direct question reflecting the damage (s) visible or invisible by deduction. Thus, it can describe a state, a situation or a damage sign, as illustrated in Figure 6.

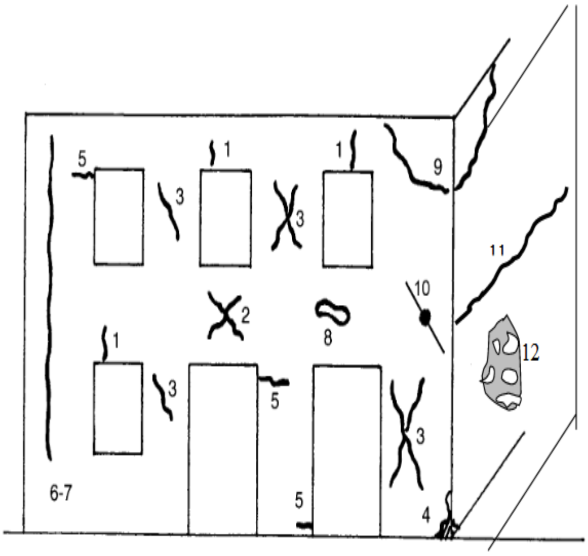

Figure 3. Example of damaged structures

When the apparent damage is not represented in a direct way by the question asked (example, the disorders of different natures manifest on the same element). This damage will be created by combination with other questions. Depending on the nature, the position, the diffusion and the disorders importance, each element is classified according to the EMS-98 scale. Then, from these different results, the constructions can be classified in three categories of different damages Table 1.

Table 1. The different damage classes

Color	V1	V2	O3	O4	R5
Symbol	D_1	D_2	D_3	D_4	D_5
Meaning	Very slight damages	Slight damages	Importants damages	Very important damages	Collapse (partial or total)

The Rules

The introduction of these models given by (Akkouche et al., 2019): for the estimation of the damage level and (Morgan et al., 2006) for the estimation of number of victim's) in the BC was made in the form of production rules, as given by the program next

- der (DER):- dep (DEP), dec (DEC), deptt (DEPTT), deti (DETI),
A is a * DEP, B is b * DEC,
C is c * DEPTT, D is d * DETI,
E is e * DEP * DEC,
F is f * DEP * DEPTT,
G is g * DEC * DEPTT,
H is h * DEP * DETI,
I is i * DEC * DETI,
J is j * DEPTT * DETI,
K is k * DEP * DEC * DEPTT,
L is l * DEP * DEC * DETI,
M is m * DEP * DEPTT * DETI,
N is n * DEC * DEPTT * DETI,
DER is A + B + C + D + E + F + G + H + I + J + K + L + M + N.
des (DES):- dees (DEES), dere (DERE), dei (DEI), deex (DEEX),
A is o * DEES, B is p * DERE,
C is q * DEI,
D is r * DEEX,
E is s * DEES * DERE,
F is t * DERE * DEI,

G is u * DERE * DEEX,
H is v * DEES * DEI,
I is w * DEES * DEEX,
J is x * DEI * DEEX,
K is y * DEES * DERE * DEI,
L is z * DEES * DERE * DEEX,
M is a1 * DEES * DEI * DEEX,
N is a2 * DERE * DEI * DEEX,
DES is A + B + C + D + E + F + G + H + I + J + K + L + M + N.
dg (der(DER), denr (DENR), DG):- der(DER), denr (DENR),
A is a3 * DER,
B is a4 * DENR,
C is a5 * DER * DENR,
DG is A + B + C + 1.
-nah (NAH) (a(i) (a(I)), rd2(RD2), rd3, d4, d5 (RD3,D4, D5), rvict (Rvict)
A is b1 * a(I)
B is b2 * RD2
C is b3 * RD3, D4, D5
D is b4 * Rvict
NAH is A+B+C-D.

Validation of the PSDIT Tool

The validation of the proposed model is established by comparing the calculated DG with PSDIT and the estimated category of DG (given in the form), on a set of ten constructions (see Table 2).

Table 2. The level of component damage.

Building Number	Damage reported on components							
	Structural				Non structural			
	D_{EP}	D_{EC}	D_{EPT}	D_{TI}	D_{ESC}	D_{ERE}	D_{EI}	D_{EE}
1	3	4	2	2	3	2	2	2
2	2	4	3	3	4	4	4	4
3	3	1	4	4	4	3	1	3
4	4	3	4	3	3	3	3	4
5	2	2	1	2	2	4	2	1
6	4	4	2	2	4	3	2	2
7	1	1	1	1	3	2	3	4
8	1	1	2	2	3	1	3	4
9	3	3	2	2	2	2	1	4
10	5	2	2	3	3	2	1	4

The constructions selected for the validation of the model come from the forms that were not used in the identification procedure (the establishment of the models). The comparison of the global damage values D_G obtained by the calculation, and those instinctively estimated by the investigators using the resemblance formula given by the EMS 98 scale definitions highlighted, the subjectivity of the evaluation process (after the Boumerdes earthquake, 2003).

Referring to the results given in Table 2, it was found that for constructions 1, 2, 4 and 7, the model reproduces the expert's decision with an insignificant margin of error ranging from [3% to 7.5%]. While, for constructions 5 and 6, the model approaches the experimental results with a percentage difference ranging from [18.7% to 26.1%], i.e. an inaccuracy of (+ or -) one degree of damage. On the other hand, the biggest difference was observed on constructions 3, 8, 9 and 10. This divergence of 33,1% with 50% demonstrates the importance of the inaccuracy, as an error of (+ or -) two or three degrees of damage is noted. Despite the fact that the same category of damage (very significant) was attributed to the first 05 constructions (see Table 3), a significant difference is noted in terms of damage recorded on the various elements (see Table 2), for example: the same decision was made for the 1st and the 5th construction (vis-à-vis the maintenance or the discontinuation of usage), whereas, in the detail of the inspection, a lag of 20% in terms of damage significance was recorded on the 1st construction compared to the 5th.

Table 3. The overall damage level

Building Number	D_G Global Damage form of evaluation	Proposed model	Gap (%)
1	4	3,88	3
2	4	4,27	6,3
3	4	2	50
4	4	3,70	7,5
5	4	3,25	18,7
6	3	4,06	26,1
7	3	3,16	5,1
8	2	2,99	33,1
9	2	3,48	43,4
10	2	3,53	42,5

Conclusion

The PSDIT use should bring great interest in the pos-seismic emergency management. Indeed, it allows non-expert engineers to benefit from the experience and skills of experts in the assessment damages field. After identification, the PSDIT classifies and processes all the information needed to manage the situation. These results are gathered in tables that include the number of damaged buildings, number of the homeless people, the number of casualties and missing people. This work is done following different scales: structure, district and city. Among the results generated by the PSDIT:

• Immediate measures, in relation to the damage levels DG of structures,

• The arrangements to be made by the authorities for the victims' management, such as, the number of reception centers in the short and long term for the homeless, the care centers for the wounded (beds number, staff number ... etc.),

• The budget estimate dedicated for the victims' compensation, since the tool can inform us about state of the structural elements and non-structural separately.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

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