
# Expert system for post-earthquake building damage evaluation and massive risk occupancy decision-making

TEAM LEADER

**Martha Liliana Carreño T.**
<liliana@cimne.upc.es>

PROJECT ADVISORS

**Omar D. Cardona**
**Alex H. Barbat**

SYMPOSIUM NOTES

## Lessons learned or important elements that will have impacts on disaster risk reduction – Colombia and worldwide

The experience in all countries has demonstrated that whenever a moderate or strong earthquake occurs, that causes widespread damage in an urban center, serious problems emerge for the processes of risk evaluation of the affected buildings. These problems have serious legal, economic and security implications. A similar situation was repeated in the case of the building damage evaluation after the earthquake of January 1999 in coffee growing area of Colombia.

These problems have appeared, partly, due to the lack of experience of the inspectors and the unavoidable need to have involving in the process non-expert people to make difficult decisions of much responsibility about the security of the buildings. Therefore, it is common, that errors are being made, like demolishing or evacuating constructions that probably were not in so serious conditions, or underestimating damage, placing in danger the life of the occupants.

Due to this situation, within the Program of Damage Evaluation, that was implemented by the Asociación Colombiana de Ingeniería Sísmica (AIS) and the Oficina Municipal de Prevención y Atención de Desastres (OMPAD) of Manizales, Colombia, it was agreed to develop a computational tool, based on Artificial Intelligence (AI) to avoid the error-making before mentioned, and with the purpose of complement the conventional methods of damage evaluation –inspection forms, guidelines and evaluation procedures– that were elaborated for risk estimation in case of an earthquake in the city.

This Expert System will help to avoid the loss of life, identify the unsafe buildings and prevent its occupation. Also, it will contribute to identify the safe places that can be used like shelters for people who have lost their homes or that have had to be evacuated. The system is a support for the decision-making by the non-expert inspectors. Then, it will facilitate the massive and right evaluation of damage, risk, habitability and reparability of buildings after an earthquake.

This system is also being implementing officially by the city of Bogotá and it is hoped that will be adopted by othre cities of Colombia with the technical support of AIS. Also, it could be used in other countries, once it become adapted in agreement with their construction classes, contributing to a fast and reliable decision making; problem of risk and disaster that must be faced and that has deep social and economic implications for the society when an important earthquake strikes.

## Summary on the implementation of the project and its results

Using techniques of Computational Intelligence (CI) an Expert System was developed, based on expert criteria, in order to employ properly subjective and incomplete information about the damage of affected buildings after an earthquake, and to carry out linguistic or qualitative qualifications about their level of risk, habitability and reparability in a reliable way. This system was designed using fuzzy sets and fuzzy logic and it was calibrated by means of an artificial neural network (ANN); modern technologies of AI suitable for the handling of vague and qualitative information.

In order to carry out the proposed tool it was necessary to participate in some activities in the framework of the Program of Damage Evaluation that was made in Colombia by AIS and the OMPAD. These activities have been fundamental for the suitable understanding of the problem and to develop a useful product, witch was not had initially into consideration within the mentioned program. These activities to develop the Expert system were:

- To participate in the review of the main existing methodologies of building damage evaluation.
- To participate in the development of the guidelines and inspection forms for buildings affected by earthquakes in Manizales city.
- To formulate the conceptual and mathematical model of neuro-fuzzy expert system based on Computational Intelligence.
- Development, calibration and test of the expert system using information from evaluations made during the January 1999 Quindio earthquake.

A summarized description of each activity is presented in the following paragraphs.

### *Review of the main existing methodologies of building damage evaluation*

The main elements for a methodology of building damage evaluation are: classification of building damage, definition of the possibilities to use the constructions that suffered damage, organization for collection of data, and the analysis and information processing. This was considered very useful to study the different methods and to compare the most recent formats and criteria of evaluation of the different methodologies with the purpose of identifying the main conceptual differences among. This activity was made partially in Barcelona within the academic activities of the author and during visits made to Bogotá, D.C. It meant the careful revision of the methodologies before mentioned, with the purpose of obtaining fundamental inputs for the development of the Expert System object of this project.

For the review of the existing methodologies a group of specialists of AIS was comprised. The author of this project was part of the group and contributed with her work related to the topic made during her graduate studies. It was carried out a bibliographical compilation on the existing methodologies of different countries. The main methodologies evaluated were from Macedonia (old Yugoslavia), USA, Japan, Mexico, Italy, Greece, Turkey, and Colombia. This review was made with the purpose of analyzing comparatively the different methodologies considering aspects such as: their objectives and scope, criteria for description and location of constructions, criteria for damage evaluation and classification, type of recommendations and emergency measures proposed, among others.

The conclusion, after a rigorous review of all methodologies, has been that the more complete approaches are: the ATC-20 from USA, the methodology developed by the Mexican Society of Seismic Engineering, the method promoted by the Ministry of the Construction of Japan and by the National Seismic Service of Italy. Also it is important to acknowledge the previous techniques developed in Colombia.

In general, the methodologies are relatively recent, in almost all countries the forms and guidelines have been updated due to the improvement of knowledge after each earthquake. The damage evaluation procedures normally are applied by different stages, which have been classified in fast, detailed and engineering evaluations, being the first two of special interest for the object of this work.

The fast evaluation of habitability of constructions is applied usually in the short term to define the possible occupation and use of the building. After the evaluation, if the buildings are safe, they can be used. In addition, some recommendations are issued with the purpose to reduce risk for their inhabitants. The detailed evaluations that describe the level of structural damage and its classification should be developed due to several reasons, but in general they are made with the objective to verify the safety level of the constructions on which there are some doubts due to a very fast evaluation or due to the lack of experience of the inspectors.

### *To participate in the development of the guidelines and inspection forms for buildings affected by earthquakes in Manizales city*

From the review of the work made in Colombia to date and other places of the world, it was possible to conclude that the existence of a detailed fast evaluation with aims of emergency response has been in order to verify doubtful evaluations or to make a look by a person with more criterion and experience to make decisions. Therefore, it was concluded that it is more efficient to apply a single evaluation form and that the inspectors teams should be comprised, at least, by two people to have a greater trustworthiness in the concepts. Also, it was possible to conclude that is better to avoid making a double evaluation and that in case of need the second professional concept would be easier if it could be made in the same form in the second visit; hoping that these cases are exceptional and not the rule. However, it was ratified that with the aid of an Expert System based on AI, made to support the decisions of less experienced inspectors, it is possible to solve this problem.

Considering the Program of Damage Evaluation that AIS and OMPAD make in Colombia, with the purpose of preparing the institutions of the city and the private sector to carry out the estimation of risk in the buildings affected in case of earthquake, the design of the inspection guidelines of constructions after an earthquake was made. Also, the damage inspection forms and the warning formats of habitability were developed. This work was carried out in a participative way with the potential users in the city and with the coordination of a team of specialists of AIS in which the author of his project was involved.

The design of the field guidelines was taking into account that the persons who will apply them will be professionals related to construction sector, like civil engineers, architects or technicians, advanced students of the same professional areas and, in general, people that will even arrive from other cities in case of an extreme event The guidelines, the inspection forms and the warnings formats of habitability are the output of the research process made with the purpose of consolidating a basic methodology useful not only for the city of Manizales but also for other cities and the national level The objective of the inspection guidelines is to have a methodology for building damage and safety evaluation that might be applied after an earthquake. This methodology allows defining the habitability of constructions quickly and facilitates the later actions of rehabilitation and reconstruction

The scope of the guidelines was limited by agreement of all participants The classification of the building damage and the habitability are based on the results of the building global inspection, the damage in the structural and non-structural elements and the ground conditions of surroundings Therefore, the guidelines do not include the procedures to evaluate the definitive rehabilitation of the construction. For this, each owner should contract a structural engineer, who makes detailed and complete inspection or carries out tests on the quality of the materials, the state of reinforcement, etc. On the other hand, it was not developed procedures to quantify the detailed economic and social impact generated by the earthquake, but with the guidelines is possible to obtain a gross estimation of the magnitude of the disaster, useful for rehabilitation and reconstruction planning

## *Formulation of the conceptual and mathematical model of neuro-fuzzy expert system based on Computational Intelligence*

In agreement with the previous remarks, the conventional damage evaluation consists on identification and registry of damage occurred in the affected buildings, with the purpose of determining in a fast way if they are at risk. In other words, if they are safe or they must be evacuated to protect the life of his occupants. This process demands experience, criterion and training; therefore, it is a need that all people involved in the process must be experts in the evaluation process. Unfortunately, the professionals who usually fulfill this requirement are very few. On the other hand, the evaluation is an urgent and massive task that should be made by several professionals and the current methodologies are not very objective if non-expert people are involved because they have the tendency to aggravate or to underestimate the real level of damage. Therefore, in the case of the Program of Damage Evaluation for Manizales, promoted by AIS and OMPAD, it was concluded about the need to complement the current methodology of damage evaluation with an innovating tool that help to solve the deficiencies before mentioned.

The evaluation of the damage and the level of risk that presents a construction after an earthquake are a complex activity that demands much criterion and knowledge and can have serious implications for security of life The information that takes part in the evaluation is highly subjective and depends on the conception and the inspector perception in each case. Mistakes can be made, such as the demolition of buildings that probably were not in so serious conditions, or buildings can be evacuated unnecessarily. Also, it is possible that non-expert inspectors ignore failures in the construction that jeopardize their stability, putting in danger the life of his occupants. For that reason it is so important to guarantee that the more experienced people and with the better knowledge on structural behavior and pathology make the evaluations.

The levels of damage in one building are defined in most of the evaluation methodologies by means of linguistics qualifications such as slight, minor, moderate, average, severe or heavy. These concepts can have a remarkable variation in their meaning according to the knowledge and experience of each person. Therefore, a defined frontier between these valuations does not exist clearly What for a person could be moderate for another can be severe, as well as it can be in the middle of both concepts for another one. For this reason it is necessary to unify the sense of these concepts and to make the evaluation more quantitative as possible, determining percentage of affected elements, size and type of cracks, etc.

In agreement with the research made by the author, using fuzzy sets it is possible to represent qualitative or subjective information in a numerical way, such as it is required in damage evaluation after an earthquake. Fuzzy sets do not have defined limits perfectly; that is to say, the transition between the membership and the non-membership of an element to a set is gradual. On the other hand, the ANNs have been used to face nonlinear complex problems, simulating the operation of the nervous system of the humans. These algorithms are demonstrating to be very useful for several applications, like pattern and image recognition, signal processing, optimization and the automatic control.

Taking into account this features a computational tool was designed that helps to avoid the mistakes usually made by non-expert people before mentioned and considering they use subjective and incomplete information In addition, this tool allows carrying out the massive and suitable evaluation of damage, habitability and reparability of buildings affected by earthquakes, being based on linguistics or qualitative qualifications, using artificial neural networks and fuzzy logic.

### *Development, calibration and test of the expert system using the information of the evaluations made during the January 1999 Quindío earthquake.*

The source code of the expert system was developed in Visual BASIC with registry modules made in Access. The computer program "Earthquake Damage Evaluation" of buildings (EDE) for Manizales runs on Windows 95, 98, 2000 or XP. The computer program is the direct product of this project.

The neural network in which the system is based was calibrated by means of a Kohonen-type learning algorithm. The learning process was made using damage evaluations achieved after the 1999 Quindio earthquake in Colombia. The training of the network did not consider structural systems such as wood and steel frames because the absence of these structural systems in the area affected by the earthquake Only few composite (frame and wall) reinforced concrete buildings were used because there are a few of them in the area.

In order to carry out correctly this training an exhaustive review of the evaluation forms used for the Ministry of Development for the census of affected buildings in the area was made. This information was analyzed with the purpose of identifying the cases (building class, levels of damage, diagnosis) and the inspectors who made the evaluations. Thus, AIS made a detailed review of the registries to develop the database for the calibration and training of the neural network. It meant also the work of experts and the administrative and logistical support of people related to AIS to collect and adjust the information

Once the system was calibrated using the database it was necessary to make several tests with hypothetical cases. They allowed to the experts verify the performance of the system Also, it was made a process of qualification and verification with local experts in Manizales city, with the purpose of exploring feasible cases and to guide the right use of the system by people who will have the responsibility to carry out the evaluations in case of an earthquake in the future, with the coordination of OMPAD.

The Expert System EDE was delivered to the city, like a complementary tool for damage evaluation, for individual and complex cases, within the Program of Damage Evaluation made by AIS and OMPAD in Manizales. At present, EDE is also implementing in the city of Bogotá, the capitol city of the country, and it now part of the Program for Post-earthquake Building Damage Evaluation that AIS develops with the Dirección de Prevención y Atención de Emergencias (DPAE) from Bogotá

The author thanks to the ProVentium Consortium by the grant. This aid has been an important support to include the doctoral research activities of the author –developed in the Technical University of Catalonia– in the Program of Damage Evaluation that is made in Colombia for the city of Manizales and Bogotá. Also the author is very grateful with the professors Alex H Barbat and Omar D. Cardona by their academic direction and with AIS due to the opportunity to be part of its program and to include the model proposed for practical application. Particularly, the author acknowledges the guidance of Omar D Cardona as president of AIS and Ana Campos as technical coordinator of the program for Manizales and of the second stage of the program in Bogotá, in execution at present.

## Brief description of the model

### *Computational model*

The presented model uses a fuzzy logic approach, required by the subjective and incomplete character of the information. Post-earthquake damage evaluations use qualitative and linguistic expressions that are appropriately handled by the fuzzy sets theory. In addition, an artificial neural network (ANN) is used to calibrate the system using the judgement of specialists. Artificial neural networks were inspired by the modelling of neural networks of natural neurons in a human brain. In this case a network with fuzzy signals is used. This enables the use of computational intelligence for the damage evaluation by non-experts.

The artificial neural network (ANN) structure of this model consists of three layers. The neurons in the input layer are grouped in four types, namely structural elements (SE), non-structural elements (NE), ground conditions (GC), and pre-existent conditions (PC). Each one contributes with information to the neurons in the intermediate layer; they only affect the intermediate neuron in the group to which they belong. The input neurons number or variables in the model is not constant; this number depends on the structural system and on the importance of the groups of variables for the evaluation. The number of neurons of the input layer used for the structural elements group changes according to the class of building. Table 1 shows the structural elements or variables considered according to the structural system.

A qualification is assigned depending on the observed damage using five possible damage levels that are represented by means of fuzzy sets. For structural and non-structural elements, the following linguistics damage qualifications are used: none (N), light (L), moderate (M), heavy (H) and severe (S). Figure 1 illustrates the membership functions for these qualifications.

**Table 1. Structural elements according to structural system**

| Structural system | Structural elements |
|---|---|
| RC frames or (with) shear walls | Columns/walls, beams, joints and floors |
| Steel or wood frames | Columns, beams, connections and floors |
| Unreinforced<br>Reinforced<br>Confined masonry | Bearing walls and floors |
| Bahareque or tapial walls | Bearing walls and floors |

Figures 2 and 3 show some damage levels in different structural and non-structural elements. The membership functions of fuzzy sets achieve their maximum membership point for the values of the damage indices whose selection will be explained forward.

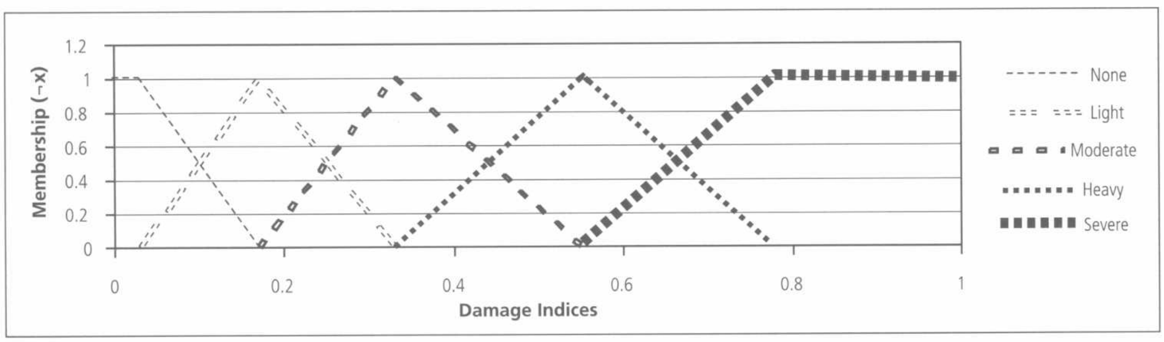


**Figure 1. Membership functions for linguistic qualifications**

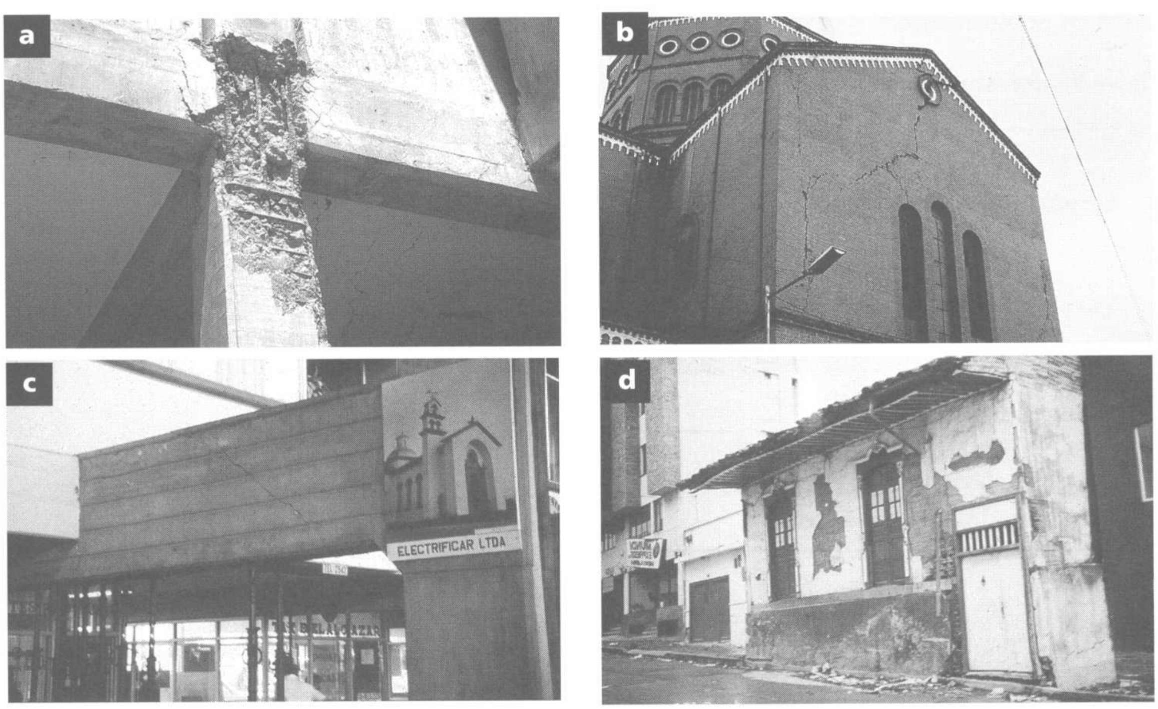


**Figure 2. Damage in structural elements.**
**a) Severe damage in a reinforced concrete joint**
**b) Moderate damage in a reinforced concrete beam**
**c) Heavy damage in a masonry wall**
**d) Heavy damage in a bahareque wall**

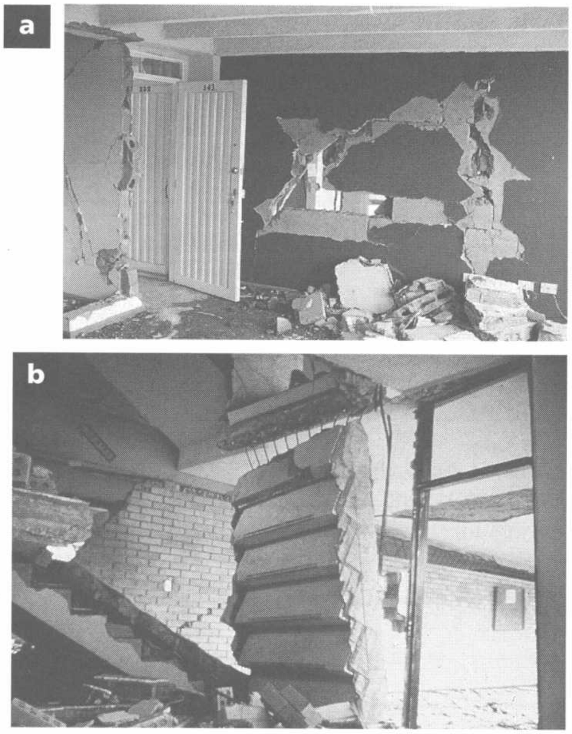

**Figure 3.**
**Damage in non-structural elements**
**a) Severe damage in partitions**
**b) Severe damage in stairs**

Damage in the non-structural elements does not affect the stability of the buildings, but may put at risk the security of the occupants. Table 2 presents the classification of the non-structural elements: elements whose evaluation is compulsory and elements whose evaluation is optional.

**Table 2. Non-structural elements**

| | |
|---|---|
| Compulsatory evaluation elements | Partition |
| | Elements of façade |
| | Stairs |
| Optional evaluation elements | Ceiling and lights |
| | Installations |
| | Roof |
| | Elevated tanks |

The ground and pre-existent conditions variables are valued through the qualification of their state at the evaluation moment. The linguistic qualifications used are: very good (VG), good (G), medium (M), bad (B) and very bad (VB). Ground conditions consist of variables that can affect the stability of the building, such as landslides and soil liquefaction; examples of these situations can be observed in Figure 4. Pre-existent conditions are related to the quality of the construction materials, plane and vertical shape irregularities of the building, and the structural configuration, illustrated in the Figure 5; these conditions may increase the seismic vulnerability of a building.

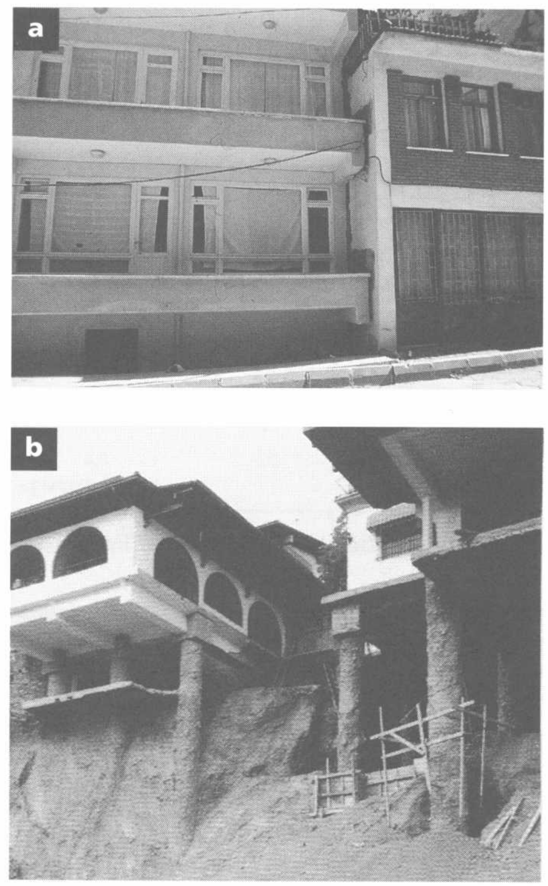

**Figure 4 Ground conditions**
**a) Soil settlement due to liquefaction**
**b) Landslides and ground failure**