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FUZZY LOGIC MODELS FOR SEISMIC DAMAGE ANALYSIS AND PREDICTION

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ABSTRACT:

This paper extends some authors' previous approaches to models and methods based on fuzzy sets and fuzzy logic, for the seismic fragility updating and seismic damage evaluation, in their contributions to the IFIP 8 Conference (Krakow – 1998), SMiRT 16 (Washington DC – 2001) and SMiRT 18 (Beijing – 2005) Conferences. A short survey of such earlier and more recent proposals for applying fuzzy concepts and methods in structural reliability and seismic damage evaluation is given in the Introduction. Basic concepts related to fuzzy sets and fuzzy logic inference rules follow in the next section. Certain applications of models based on fuzzy logic to the seismic damage assessment of RC structures are presented in the third section. The fuzzy rule bases are involved in the estimation of a damage index corresponding to the damage state of the structure by means of a de-fuzzification process. It is also discussed a fuzzy logic based method (due to S.K. Deb and G.S. Kumar) for estimating the level of seismically induced damages by use of certain damage indices. Other recent models based on fuzzy logic for the seismic damage assessment and control are also discussed, with emphasis on the fuzzification / defuzzification techniques. Applications to the seismic damage assessment of RC structures by means of fuzzy logic models are approached next.

KEYWORDS: earthquake damage assessment and prediction, fuzzy logic, fuzzy inference rules

1. INTRODUCTION

A large variety of (earthquake-induced) damage indices or damage functionals were proposed, and they naturally depend on the nature of the structure under study or design, and also on the nature of adverse actions from the environment. In many cases, it is (at least) difficult to evaluate numerically a certain damage index for a given structure or component subjected to ground motions. Instead, the so-called "linguistic variables" were used for describing the damage state of a structure. The latter one proved to be adequately characterized in terms of models based on fuzzy sets and fuzzy logic. Early endeavours for working out and using fuzzy models for structural damage analysis and prediction go back to mid 70's and early 80's with some papers due to classic authors like J.T.P. Yao, D.I. Blockley and a.o. [the first three references in Ref. list]. Subsequently, relevant contributions have also been brought by Chinese and Indian authors [Liu et al. 1984], [Deb & Kumar 2004].

Several contributions to the previous (13th) WCEE held in Vancouver came with new ideas and methods – involving fuzzy logic and fuzzy sets – for the structural safety assessment of damaged RC structures, for active control systems on seismically excited structures, etc. Some basic concepts related to fuzzy sets and fuzzy logical inference are presented in the next section. Applications to the seismic damage assessment of RC structures by means of fuzzy logic models are approached next. Five limit states were selected for evaluating the quality of (in situ) concrete components, in terms of various degrees of damage. The fuzzy rule base is then settled, and a damage index corresponding to the damage state of the structure is estimated by application of the de-fuzzification process. There are also proposed extensions of this fuzzy method, due to S.K. Deb and G.S. Kumar (2004) to the use of other damage indices known from the literature on the seismic damage analysis and evaluation. In the last section of the paper, the authors discuss some recent contributions to the active control systems for seismically excited structures using fuzzy logic techniques (due to S. Qiu & R.J. Scherer), and to fuzzy seismic damage assessment [S.K. Deb & and G.S. Kumar 2004]. Alternative fuzzy membership functions are proposed for a better description of the ground motion parameters and of the control force.

2. FUZZY SETS AND FUZZY LOGIC INFERENCE

The original definition of fuzzy (sub)sets emerged from the idea of extending the definition of the characteristic (or indicator) function of a subset. Thus, if U is a set and $\mathcal{P}(\mathrm{U})$ is the set of its subsets, then the membership of an element x in U to a subset $S \in \mathcal{P}(\mathrm{U})$ or $S \subseteq \mathrm{U}$ can be characterized by means of a function $\chi_S : \mathrm{U} \to \{0,1\}$ as follows **:**

$$\chi_S(x) = \begin{cases} 1 & \text{if} \quad x \in S, \\ 0 & \text{if} \quad x \notin S. \end{cases} \tag{2.1}$$

Thus, the set of all subsets of U is in 1-to-1 correspondence with all the $0-1$ valued functions of the form in Eqn (2.1). The fuzzy subsets of U are, in principle, defined by means of membership functions taking values in the whole interval $[0,1]$ and not only at the ends of this interval. Such functions are usually denoted by μ_S; hence a fuzzy membership function is a mapping of the form

$$\mu_S : \mathrm{U} \to [0,1]. \tag{2.2}$$

For any x in U the real number $\mu_S(x)$ may be regarded as the degree of membership of x to the subset S. A more general definition of the fuzzy sets can be obtained by taking a *lattice* $\mathcal{L}$ with 0 & 1 as the minimum, respectively maximum element, instead of the interval $[0,1]$. A *Boolean algebra* $\mathcal{B}$ (with the distributivity of $\wedge, \vee$ operations with respect to each other, with the complementary operation defined by $a \vee \bar{a} = 1,\ a \wedge \bar{a} = 0,\ \bar{1} = 0,\ \bar{0} = 1$) instead of a lattice is considered in some references. For any element a in a Boolean algebra $\mathcal{B}$ it is satisfied the inequality $0 \le a \le 1$; thus $\mathcal{B}$ is a generalization of the real interval $[0,1]$ with the linear order induced by the linear (or total) order relation on $\mathbb{R}$. A fuzzy (sub)set of U defined by means of a membership function as in Eqn (2.2), with $[0,1]$ replaced by $\mathcal{B}$, is called a $\mathcal{B}$–fuzzy set. The choice of the membership function is $-$ up to a point $-$ a matter of subjective choice.

In practical applications of fuzzy models to problems like the state of damage evaluation for a structural system, a damage parameter is considered whose range is a set U of real numbers. In most cases this is just an interval, and if the damage functional is normalized then it is just the unit interval $[0,1]$. Then a number in U may be regarded as a fuzzy number if it is a central point in a fuzzy set. An example is given in [Carausu & Vulpe 2001] for the strength capacity of a structure estimated to be (most likely) equal to 20000 kN. This would be a "crisp" number, but it is more realistic to consider it as the most probable value of a fuzzy number taking values in the interval $[19000, 21000]$. The fuzzy representations of this fuzzy / crisp number are plotted in Fig. 1 **- a)** & **b)**, respectively.

The fuzzy subsets are often assimilated to fuzzy numbers and a specific "fuzzy arithmetic" is formulated to allow for operations with fuzzy numbers, and thus with fuzzy sets. If a fuzzy S set is represented by a polygonal line defining its membership function μ_S (the triangular representation in Fig. 1 gives an example) and x_i are the points where this line changes its slope then S can be represented as a formal sum of the form

$$S = \sum \mu(x_i) | x_i . \tag{2.3}$$

The fuzzy set in Fig. 1 will thus be represented by the fuzzy set 'capacity' written as $C = 0 \,|\, 19000 + 1 \,|\, 20000 + 0 \,|\, 21000$. Graphically speaking, a point x_i as those that occur in (2.3) is a point at which the polygonal line describing the membership function μ_S changes from a line segment to another, of a different slope.

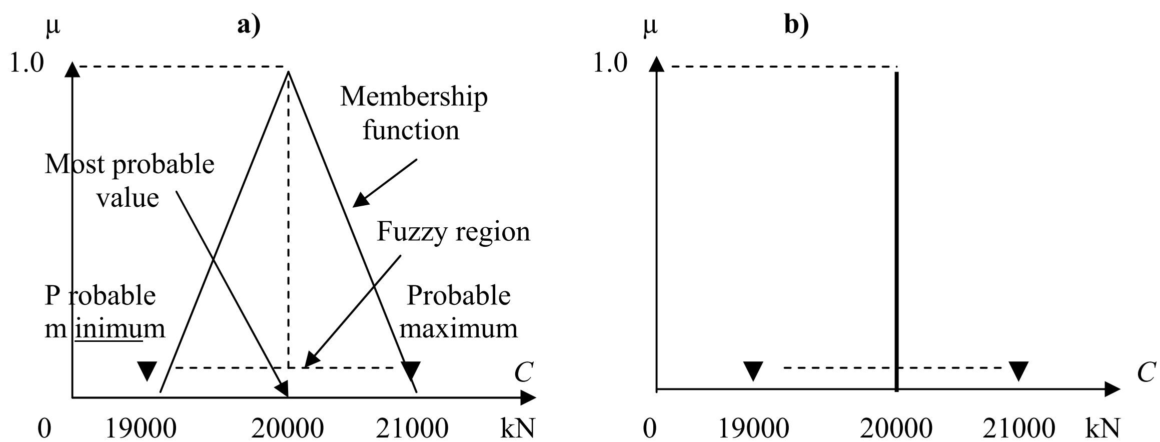

Figure 1 Typical representations of a fuzzy and a crisp number by fuzzy membership functions

If S and T are fuzzy sets with their membership functions μ_S & μ_T then their *fuzzy union* and *intersection* are usually defined by means of a membership function as follows **:**

$$S \cup T : \mu_{S\cup T}(x) = \mu_S(x) \vee \mu_T(x),\ x \in \mathrm{U}, \tag{2.4}$$

$$S \cap T : \mu_{S\cap T}(x) = \mu_S(x) \wedge \mu_T(x),\ x \in \mathrm{U}, \tag{2.5}$$

where $\vee$ and $\wedge$ are (respectively) the max and min operators. The algebraic product $S \cdot T$ and the algebraic sum $S + T$ of two fuzzy subsets of $\mathrm{U} \subseteq \mathbb{R}$ are respectively defined by the corresponding membership functions

$$\mu_{S\cdot T} = \mu_S \mu_T,\ \mu_{S+T} = \mu_S + \mu_T - \mu_S \mu_T. \tag{2.6}$$

The similarity of the rules in Eqns (2.6) with the rules giving the probability of the intersection of two (independent) events and of the union of two events is obvious.

Let now f be a mapping from U to V $(f : \mathrm{U} \to \mathrm{V})$ and $S \subseteq \mathrm{U}$ a fuzzy set with the membership function μ_S. Then the image of $S \subseteq \mathrm{U}$ through f is the set with the membership function

$$\mu_{f(S)}(x) = \begin{cases} \sup\{f(x) : x \in f_{-1}(y)\} & \text{if } f_{-1}(y) \neq \varnothing, \\ 0 & \text{otherwise.} \end{cases} \tag{2.7}$$

If $T \subseteq \mathrm{V}$ is a fuzzy set with the membership function μ_T then its *counterimage* through f is the fuzzy subset of U with

$$\mu_{f_{-1}(T)}(y) = \mu_T\big(f(x)\big). \tag{2.8}$$

We use -1 as a subscript (and not as a superscript) since f needs not be invertible, in general. The term of "logical intersection" is used in [Carausu & Vulpe 2001] for the intersection of two fuzzy sets defined by Eqn (2.5). We illustrate, in Figure 2, the union and the intersection of two fuzzy sets.

This simple example shows that the graph of a fuzzy membership should not be always triangular. In general, it is a polygonal line. This is the case with $\mu_{S\cup T}$ in Fig.2. Moreover, not only the resulting $\mu -$ functions for fuzzy sets obtained through certain operations may have other than triangular shapes but just the initially adopted functions may be, for instance, trapezoidal ; this is the case with the $\mu -$ functions that describe the small and large peak ground accelerations in [Deb & Kumar 2004]. We may only state two general conditions on the shape of the graphs of membership functions : they should be univalued polygonal lines included in the rectangle $I \times [0,1]$ with I = a finite interval included in $\mathrm{U} \subseteq \mathbb{R}$. The height of a specific μ - function should not be necessarily $=1$ but only ≤ 1. There exists a degree of subjectivity in selecting the shape of the membership functions to describe certain fuzzy subsets, and just this requires to take into account the possibility to (suitably) update the prior shapes of these functions after newly acquired observation data on the parameter which is analyzed.

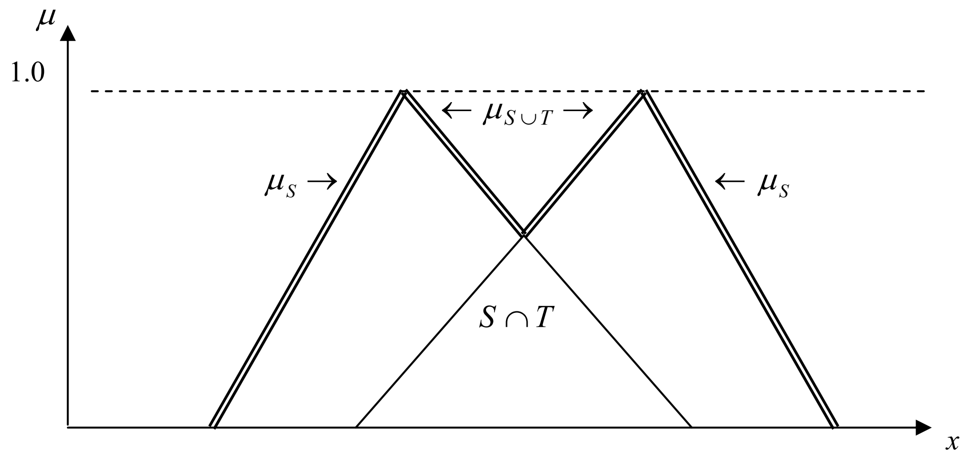

Figure 2 The union and the intersection of two fuzzy subsets

Fuzzy logical (or inference) rules were also formulated in several papers related to seismic risk assessment. We do not intend to give a detailed presentation of a FUZZY LOGIC. There exist various ways to introduce fuzzy logical rules. Let us mention the approach of [Liu *et al* 1984]. Starting from the necessity to evaluate the spectral intensity of ground motion in terms of "linguistic" values (from small to large), a general form of a fuzzy inference rule is proposed ; it is expressed in terms of several variables and – in fact – it consists of a set of m rules **:**

$$\text{IF } (x_1 \text{ is } A_{i,1}) \text{ and } (x_2 \text{ is } A_{i,2}) \text{ and } \ldots \text{ and } (x_n \text{ is } A_{i,n}) \text{ THEN } (y \text{ is } B_i),\ i = \overline{1,m}. \tag{2.9}$$

The variables x_i can be observed values of the ground motion parameters like the PGA a_g or spectral intensity SI while y is a damage measure. After estimating local damage measures, these are assembled into global fuzzy sets by means of weighted sums.

In a more general approach, a fuzzy logical system is built on a set $V = \{v_1, v_2, \ldots, v_n\}$ of logical values, and a truth function is defined on V, $\tau : V \rightarrow [0,1]$. The set $\mathcal{F}$ of formulas of the fuzzy logic is built up in a classical way : (*i*) any variable is a formula, (*ii*) if F is a formula then non-F is a formula, (*iii*) if F, F' are in $\mathcal{F}$ then $F \vee F'$ and $F \wedge F'$ are also in $\mathcal{F}$, (*iv*) $\mathcal{F}$ consists of the formulas obtained by (*i*), (*ii*) and (*iii*) only. Here $\vee$_is the logical disjunction, $\wedge$ denotes the logical conjunction and non-F is also (sometimes) denoted by $\overline{F}$. The truth function is extended from logical values to formulas by the rules

$$\begin{cases} F = v_i \Rightarrow \tau(F) = \tau(v_i), \\ \tau(F \wedge F') = \min\{\tau(F), \tau(F')\}, \\ \tau(F \vee F') = \max\{\tau(F), \tau(F')\}, \\ \tau(\overline{F}) = 1 - \tau(F). \end{cases} \tag{2.10}$$

A logical formula F is said to be *valid* / *inconsistent*, if $\tau(F) > 1/2$, respectively if $\tau(F) < 1/2$. The two complementary properties are similarly defined for logical propositions or sentences. Obviously, this "separation" under valid and inconsistent formulas is questionable since, for instance, $\tau(F) = 0.503$ and

$\tau(F') = 0.498$ would classify the former formula as a valid one while the latter as an inconsistent. Instead, two formulas with the respective truth values of 0.503 & 0.995 would be both valid although the difference between their truth values is very large.

3. FUZZY REPRESENTATION OF SEISMICALLY INDUCED DAMAGE STATES

The evaluation of the damage level for a given structure is often expressed in terms of qualitative (or linguistic) variables. For instance, a five level scale is

(no damage, minor damage, moderate damage, severe damage, collapse). (3.1)

The first damage level is sometimes taken wider, that is no damage or insignificant damage. If we conventionally represent these five levels by integers (0, 1, . . . , 4) and if the damage states are evaluated in terms of a damage indicator (or damage measure) D taking values $d \in I$, where I is an interval called the support of D, then a fuzzy model can be built by defining a membership function $\mu : I \to [0,1]$. For each damage level $\ell \ (0 \le \ell \le 4)$ it has to be selected a specific interval,

$$I_\ell = [\delta_\ell^{\inf}, \delta_\ell^{\sup}], \ \ell = \overline{0,4} \text{ such that } \bigcup_{\ell=0}^{4} I_\ell = I. \qquad (3.2)$$

The natural conditions on the endpoints of the intervals that occur in the union of (3.2) are

$$\delta_\ell^{\inf} \le \delta_\ell^{\sup}, \ \ell = \overline{0,4} \text{ and } \delta_{\ell+1}^{\inf} \le \delta_\ell^{\sup}, \ \ell = \overline{0,3}. \qquad (3.3)$$

Such conditions are implicitly accepted in the most references on fuzzy models for damage evaluation, although not explicitly stated. Let us remark that the first inequality in Eqns (3.3) may be an equality, that is the corresponding interval may be reduced to a point, when the respective value is accepted as a crisp number. The second inequality in Eqns (3.3) allows the intervals in the union of Eqn (3.2) to overlap. In other words, some values $d \in I = [a, b]$ may correspond to different (but neighbor) damage levels. The membership function μ is analytically defined on each interval I_ℓ so that its graph is a polygonal line. The most usual shapes are triangular or trapezoidal (as we have earlier mentioned). If the height of each of these triangles or trapeziums is taken = 1, then the general analytic expression of μ over I_ℓ can be written as

$$\mu(x) = \begin{cases} 0 & \text{for} \quad x \le x_\ell^{\inf} \text{ or } x \ge x_\ell^{\sup}, \\ (x - x_\ell^{\inf}) / (\underline{x}_\ell - x_\ell^{\inf}) & \text{for} \quad x \in [x_\ell^{\inf}, \underline{x}_\ell], \\ 1 & \text{for} \quad x \in [\underline{x}_\ell, \overline{x}_\ell], \\ 1 - (x - \overline{x}_\ell) / (x_\ell^{\sup} - \overline{x}_\ell) & \text{for} \quad x \in [\overline{x}_\ell, x_\ell^{\sup}]. \end{cases} \qquad (3.4)$$

Regarding this analytical expression of a μ - function, a couple of remarks are necessary. **1°** We have written it for a generic fuzzy variable x instead of a damage parameter d, since a fuzzy model may be accepted for other parameters like the ground motion intensity (magnitude, spectral acceleration, etc.); we let the subscript ℓ to take values in {0, 1, . . . , m }, thus allowing for $m+1$ intervals to occur in a union of the form in Eqn (3.2). **2°** The underlined / overlined values are the points inside the interval I_ℓ where the polygonal (trapezoidal) line changes its slope **:** from a positive one to 0 {for the value 1) and from the latter to a negative slope. The general inequality between the four values in an interval I_ℓ is

$$x_\ell^{\inf} \le \underline{x}_\ell \le \overline{x}_\ell \le x_\ell^{\sup}. \qquad (3.5)$$

3° Then, it is easy to see that the second line in the right-hand side of Eqn (3.4) should be deleted if $\ell = 0$, when $x_0^{\inf} = \underline{x}_0 = a$; similarly, the fourth line will not appear if $\ell = m$, when $\overline{x}_m = x_m^{\sup} = b$. We present, in Fig.3 that follows, a fuzzy model with five fuzzy sets that cover the interval [0 , 1]. Two of them are trapezoidal, two of them are triangular and we also considered a crisp number.

A fuzzy membership function can be considered as an approximation to a probability distribution function. For instance, the *pdf* of a normal random variate $X \in \mathsf{N}(m,\sigma)$ can be approximated by a triangular μ - function if its standard deviation σ is small while a trapezoidal shape would result in a better approximation for a larger σ. In both cases, the graph of μ should be symmetric with respect to the vertical line of equation $x = m =$ the expectation of X.

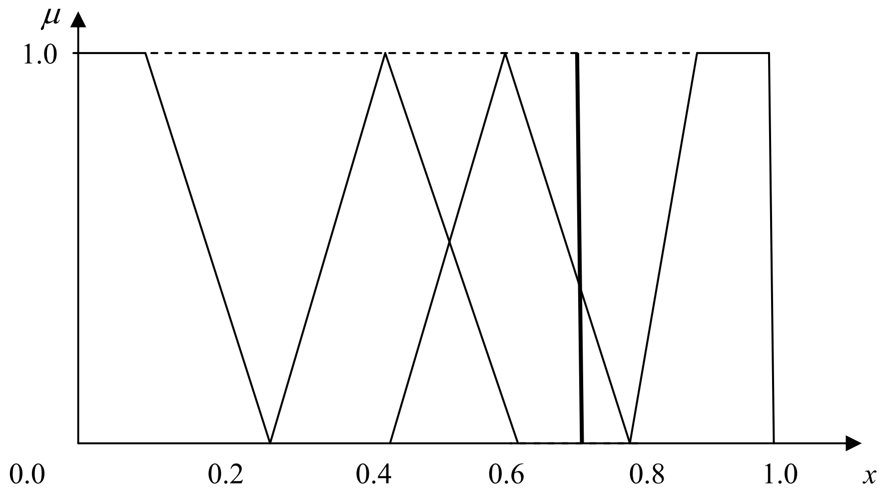

Figure 3 Five fuzzy subsets of various shapes over [0,1]

As we have earlier mentioned, fuzzy models may be employed both for the representation of the structural damage level and of the ground motion parameters. For instance, the natural period T (in sec) of deep soft soil is modeled by a fuzzy number in [Deb & Kumar 2004]. In general, if X denotes an input (seismic motion parameter) and Y is a response or damage parameter then four possible approaches are, in principle, possible **:**

$$(i): [\,\mathsf{P}\,|\,\mathsf{P}\,]; \qquad (ii): [\,\mathsf{P}\,|\,\mathsf{F}\,]; \qquad (iii): [\,\mathsf{F}\,|\,\mathsf{P}\,]; \qquad (iv): [\,\mathsf{F}\,|\,\mathsf{F}\,]. \tag{3.6}$$

In (3.6) P means *probabilistic* while F stands for *fuzzy*. We have used the conditioning line for suggesting that the damage level reached by a system is conditional on the intensity of the ground motion. The "classical" seismic damage fragility / seismic vulnerability models are purely probabilistic, meaning that they evaluate the conditional probabilities of events of the form $[Y \geq y \,|\, X = x]$. An approach of type (iv) could be said to be *purely fuzzy*, like the one in [Deb & Kumar 2004]

The approximation of the *pdf* f by a fuzzy membership function μ should follow some restrictions. The interval over which $\mu > 0$ is necessarily finite while a probability distribution like the Gaussian (or normal) *pdf* is > 0 over the whole real axis. As regards the characteristic property of a *pdf* that the area under its graph is $= 1$ cannot be satisfied by a μ - function. However, a condition of approximately equal areas may be stated for a scaled *pdf* to the $[0\,,\,1]$ interval, that is for $f\,/\,M$ where M is the (absolute) maximum value of f. Such conditions may be stated as follows **:**

$$f(x)/M = \mu(x) \neq 0 \text{ for } x \in I = [q_{0.05}, q_{0.95}],\ \frac{1}{M}\int_{\mathbb{R}} f = \int_{I} \mu \tag{3.7}$$

where $q_{0.05}$ & $q_{0.95}$ are the corresponding percentiles of the distribution with the *pdf* *f*. Certainly, the particular shape of μ will be chosen so that the corresponding polygonal line be as close as possible to the graph of f. The value of the fuzzy function μ in Eqns (3.7), outside the interval $I = [q_{0.05}\,,\,q_{0.95}]$, are taken = 0 what means that the "tails" of the actual probabilistic distribution of the corresponding (damage / seismic input) parameter are neglected.

The fuzzy representation of the seismically induced damage state of a structure or – more relevant – of a class of similar structures located in a seismologically homogeneous area has to follow the following main steps **:**

1. Selection of a vector $\mathbf{x} = (x_1, x_2, \ldots, x_k)$ of structural, ground motion and soil type parameters which are considered as relevant to the damage state assessment.
2. On the basis of seismic hazard analysis, a fuzzy distribution is established for each component x_i of $\mathbf{x}$ in terms of a specific membership function $\mu_j, 1 \le j \le k$.
3. Selection of a damage state indicator d and its modeling by a fuzzy distribution μ_D over a scale of m damage severity levels.
4. Statement of a set $\mathcal{R}$ of fuzzy logic rules of the form in Eqns (2.9) to assess the damage level for possible fuzzy (or crisp) values of input parameters.
5. Final assessment of most likely damage states induced by possible earthquakes of specific intensity classes.

A couple of remarks are necessary regarding these steps. 1) Some of the parameters in **x** may be crisp or statistically described by a mean (expected) value and a standard deviation. For example, the yield strength of typical RC members has been extensively studied and probabilistic evaluations are available. If a purely fuzzy approach is adopted then the respective probabilistic distributions can be rather easily modeled by fuzzy membership functions (as we have suggested – see Eqn (3.7)). 2) The fuzzy distribution of the damage severity depends on the number $m+1$ of damage levels adopted. The five level scale is most often used.
3) The selection of the fuzzy logic rules in $\mathcal{R}$ is the key step of a fuzzy approach to seismic damage assessment. In fact, this would correspond to the conditional distributions used in seismic fragility and vulnerability models. It is not possible to propose a general pattern for selecting these logical rules. Basically, they should be derived from the mechanical model adopted for the structural response to seismic actions. Formulas as those in Eqns (2.7) and (2.8) can be used for deriving analytical expressions for the fuzzy distribution of the output (damage) parameter d.

Certainly, the fuzzy representations of the damage state levels, just considered and discussed in this section, do not render some specificity with respect to the source(s) of damages. More precisely, a scale of damage levels as the one in Eqn (3.1) may describe the damage state of a structure / system involved by other types of factors or adverse actions, including the ageing.

4. FUZZY INFERENCE RULES FOR RESPONSE CONTROL AND PREDICTION

The contribution [Deb & Kumar 2004] to the ***13 WCEE*** Conference proposes a method for seismic damage assessment based on fuzzy logic rules. We discussed some mathematical aspects of the fuzzy models there implied in [Carausu & Vulpe 2005]. The FLDS (*Fuzzy Logic Decision System*) includes a *Fuzzy Rule Base* and a *Fuzzy Inference Engine*, but these modules interact with a *Fuzzification Module* and a *Defuzzification Module*. The form of an inference rule appears as a particular case of a rule as in Eqn (2.9). It involves two input variables of the fuzzy controller, x_i and y_i while u_i is the output of the fuzzy controller device. Rule (1) in [Qiu & Scherer 2004] looks like

$$R_j : \text{ IF } (x_i \text{ is } A_i^j) \text{ and } (y_i \text{ is } B_i^j) \text{ THEN } (u_i \text{ is } C_i^j),\ j = \overline{1,n}. \tag{4.1}$$

In (18), R_j denotes the j-th rule of the fuzzy inference rule set, x_i and y_i are the inputs of the fuzzy controller, A_i^j and B_i^j are the linguistic values associated with x_i and y_i of rule R_j ; u_i is the output of the fuzzy controller and C_i^j is the fuzzy singleton function defined by the designer. In [Qiu & Scherer 2004], the input (or – more precisely – the antecedent) parameters were chosen as the relative velocity of structural vibration $x = \dot{x}$ and the ground acceleration $y = \ddot{x}_0$ while the consequent parameter u is the fuzzy set (or value) of the control force. As remarked by the two authors, general control rules do not exist for structural vibration control. Trial-and-error methods have to be employed to estimates based on experts' opinions / knowledge. A fuzzy inference rule set is presented, in [Qiu & Scherer 2004], by means of a double entry (structural response velocity x ground acceleration) table whose entries are the consequent values of the parameter u. It is possible to express such fuzzy inference rules in a formal way as follows **:**

$$R_j(x_i = A_i^j, y_k = B_k^j) = (u_{ik} = C_{ik}^j),\ 1 \le i \le \ell, 1 \le k \le m, 1 \le j \le n. \qquad (4.2)$$

The subscripts i & k in (4.2) correspond to the linguistic values they may take. In a vibration control system based upon fuzzy inference, an essential component is the *defuzzification module* that has to convert a fuzzy output set to an output crisp value for the feedback force. The *center of gravity* of *centroid* concept is often used and it is based on the formula

$$u^* = \left(\sum_{j=1}^{n} w_j u_j\right) / \left(\sum_{j=1}^{n} w_j\right) \qquad (4.3)$$

where u^* is the crisp control output value, n is the total number of rules and w_j is a weight implying the truth value of the j-th rule. .

5. CONCLUSIONS

A couple of our earlier concerns on the employment of fuzzy models for seismically induced damage assessment have been continued in this paper. We have compared and discussed some earlier proposed fuzzy models for damage assessment with more recent models of this nature, including fuzzy models for active vibration control. We have been more concerned with certain mathematical aspects of fuzzy models, and we suggest that more formalized criteria for building the fuzzy inference rules would have to be found and used. Anyway, the approaches based upon fuzzy models for both analysis / evaluation and control of seismically induced damages probably deserve a wider attention and use. The methods based on fuzzy sets and fuzzy logic allow to incorporate the (so-called) subjective yet relevant information on both input – seismic – ground motion and the levels of damage thus induced. They turn the “linguistic” values into fuzzy distributions that can be employed in fuzzy inference rules for seismic damage assessment and prediction.

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