A FUZZYFICATION PROCEDURE FOR THE IDENTIFICATION OF DAMAGE POTENTIAL IN SEISMIC ACCELEROGRAMS

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ABSTRACT:

This study presents three fuzzy techniques for the classification of the damage potential of seismic accelerograms. The first method uses a pattern recognition algorithm for the classification of the accelerograms in four damage classes (low, medium, large and total). With the second technique the seismic time-acceleration diagram is replaced by its intensity parameters. The processing of the parameter diagram follows the procedure of the first fuzzy technique. In the third method the fuzzyfication of the intensity parameters takes place using suitable membership functions, which represent the damage classes. Their position is based on a training amount of accelerograms with known damage potential. Each parameter is connected to a membership function, which expresses the similarity to the appropriate damage class. Finally, the average value of the membership functions for the individual damage classes is calculated and their maximum value indicates the class, to which the accelerogram belongs. The three techniques are applied to a reinforced concrete frame. For the numerical analyses 400 accelerograms were used. The maximum inter-story drift ratio served as global damage indicator. Twenty seismic parameters are used in the calculation. Using the first proposed technique, the results indicate an error rate up to 62 % with the damage classification. On the other hand, the rates of the correct damage classification with the second and third techniques are substantially improved up to 84 %.

KEYWORDS: Fuzzy methods, damage indicators, seismic parameters

1. INTRODUCTION

Observation of damages on buildings after strong earthquakes and numerical investigations [Elenas and Meskouris, 1999] showed that these correlate with different seismic parameters. Thus in reverse, the seismic parameters can express the damage potential of an earthquake. In this connection, the individual damage potential for a specific construction is meant. Damage indicators can quantify the damage of a building and they are specified by nonlinear dynamic calculations. In the present numerical simulation the respective seismic loads are represented by accelerograms. The response parameters of the calculations depend on the load. Since seismic time acceleration histories can be expressed only heavily by a function, seismic parameters serve for their indirect description. Thus, a relation between the seismic parameters and the response parameters of the nonlinear dynamic calculations is established. In particular the attention focuses on the maximum inter-story drift ratio, which serves as global damage indicator. As well known fuzzy techniques are successfully used during the pattern recognition of different objects and other applications [Bourland and Morgan, 1994], [Chen et al., 1994], [Lam and Yan, 1994], [Kuncheva, 2000]. This paper investigates alternative fuzzy techniques, in order to determine the damage class of the used damage indicator by means of the seismic parameters, without accomplishing nonlinear dynamic calculations. The following structural damage classes are selected: low (no or low damage), medium (reparable damage), large (irreparable damage) and total (part or total failure).

2. SEISMIC PARAMETERS

As described in the introduction, in the last decades, researchers have been interested in relating the structural and architectural damages caused by seismic wave propagation with parameters associated to ground motion intensity. In detail the following parameters are considered: the peak ground acceleration (PGA) a_{max}, the peak ground velocity (PGV) v_{max}, the term a_{max}/v_{max}, the Arias intensity (AI), the root mean square acceleration (RMS_a), the strong motion duration as defined by Trifunac and Brady (SMD) $T_{0.90}$, the seismic power $P_{0.90}$, the spectral intensities after Housner (SI_H), after Kappos (SI_K) and after Martinez (SI_M), the effective peak ground acceleration (EPA) and its maximum value (EPA_{max}), the spectral total seismic energy input E_{inp}, the cumulative absolute velocity (CAV), the seismic damage potential after Araya and Saragoni, the central period (CP), the spectral acceleration (SA), the spectral velocity (SV), the spectral displacement (SD) and the seismic intensity as defined by Fajfar, Vidic and Fischinger (I_{FVF}). The used spectral values are calculated for the period 1.18 s. It corresponds to the eigenperiod of the examined reinforced concrete frame. The definitions of the particular parameters are indicated in the literature [Jennings, 1982], [Fajfar et al., 1990], [Elenas and Meskouris, 1999], [Meskouris, 2000] and are not here repeated. The seismic intensity parameters can be classified in peak parameters (like PGA, PGV and (a_{max}/v_{max}), in spectral parameters (like SA, SV and SD) and in energy parameters (like E_{inp} and Arias intensity). The calculation of the parameters took place via a computer-aided processing of the accelerograms. The present study uses recordings of ground accelerations from world-wide regions with well-known strong seismic activity.

3. DAMAGE INDICATOR

In the present investigation comes the maximum inter-story drift ratio (MISDR) as global damage indicator to application. This index is simple to calculate and characterize both the structural and the architectural (non-structural) damage satisfactorily. Observations of building damage after strong earthquakes and numerical investigations manifest the effectiveness of this indicator [Elenas and Meskouris, 2001]. Inter-story drift is the relative displacement of one story relative to the other. Here, the inter-story drift is noticed as u. The relationship (1) defines the maximum inter-story drift ratio (MISDR) as the ratio of the maximum absolute inter-story drift $|u|_{max}$ to the inter-story height h:

$$MISDR = \frac{|u|_{max}}{h} 100\ [\%] \tag{1}$$

Table 1 shows the range limits of the four damage classes, using the maximum inter-story drift ratio, for structural and architectural damage, respectively [Gunturi and Shah, 1992].

Table 1. Range limits of the damage classes

	MISDR range limits of the damage classes [%]	
Damage grade	**Damage type**	
	Structural	**Architectural**
Low	≤ 0.5	≤ 0.5
Medium	$0.5 < MISDR \leq 1.5$	$0.5 < MISDR \leq 1.2$
Large	$1.5 < MISDR \leq 2.5$	$1.2 < MISDR \leq 1.7$
Total	> 2.5	> 1.7

4. APPLICATION

The reinforced concrete frame structure shown in Fig. 1 has been designed according to the rules of the recent Eurocodes for structural concrete and aseismic structures, EC2 and EC8. The cross sections of the beams are considered as T-beams with 40 cm width, 20-cm plate thickness, 60 cm total beam height and 1.45 m effective plate width. The distances between each frame of the structure have been chosen to be 6 m. According to the EC8 Eurocode the structure has been considered as an "importance class III, ductility class M"-structure. Furthermore, the subsoil was of type B and the region seismicity of category I after the Eurocode EC8. In this procedure apart from the self weight and seismic loads, the snow, the wind and the live loads have been taken into account. The eigenperiod of the frame was 1.18 s.

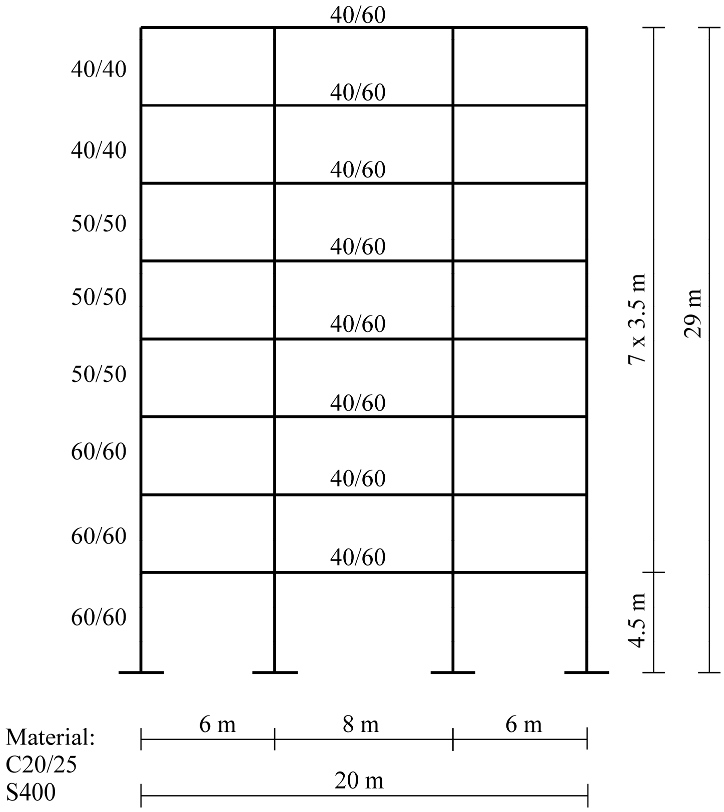

Figure 1. Reinforced concrete frame structure

After the design procedure of the reinforced concrete frame structure, a nonlinear dynamic analysis has been carried out for the evaluation of the structural seismic response. For this purpose the computer program IDARC [Valles et al., 1996] has been used. This program uses the Newmark’s incremental solution algorithm, combined with the iterative method after Newton and Raphson. The hysteretic behavior of beams and columns has been specified at both ends of each member using a three-parameter Park model. This hysteretic model incorporates stiffness degradation, strength deterioration, non-symmetric response, slip-lock and a tri-linear monotonic envelope. The parameter values, which specify the above degrading parameters, have been chosen from experimental results of cyclic force-deformation characteristics of typical components of the studied structure. Thus, the nominal parameters for stiffness degradation and strength deterioration have been chosen [Valles et al., 1996].   From the different response values, which the program calculates, the focus is on the maximum inter-story drift ratio as the global damage indicator of the structure, since this represents the summation of the damage into only one value. The damage indicator is calculated for 400 accelerograms. The present investigation utilized acceleration records from world-wide regions with strong seismic activity. The Tables 2 and 3 show the number of used accelerograms per country and per PGA-range.

Table 2. Number of used accelerograms per country

Country	Number of accelerograms
Bulgaria	2
Canada	9
Chile	12
Greece	54
Japan	46
Mexico	10
New Zeeland	2
Romania	4
San Salvador	6
Turkey	8
USA	247

Table 3. Number of used accelerograms per PGA-range

PGA-range [g]	Number of accelerograms
0.01 - 0.1	23
0.1 - 0.2	165
0.2 - 0.3	103
0.3 - 0.4	50
0.4 - 0.5	32
0.5 - 0.6	13
0.6 - 0.7	7
> 0.7	7

5. FUZZY MODELING

After the calculation of the global damage indicator (MISDR) and its classification in the damage classes according with the limiting values indicated in Table 1, an investigation follows in order to achieve the same classification, without carrying out nonlinear dynamic analyses. For this reason three alternative fuzzy techniques are used. In the present investigation both, for the training phase and for the application phase all 400 accelerograms were considered. The first method uses a pattern recognition algorithm for the classification of the accelerograms in the four damage classes (low, medium, large and total). The process is based on given similarities of the seismic time acceleration diagrams [Lazzerini and Marcelloni, 2001]. First, the scaled (on the maximum values of the time and acceleration of all signals) accelerogram diagram is decomposed in sub-regions (Fig. 2). For this purpose a genetic algorithm is applied. It follows the calculation of the relative presence level of seismic acceleration values in each sub-region. This procedure corresponds to the fuzzy representation of the accelerograms. Seismic time acceleration diagrams with well-known damage potential serve the definition of the fuzzy model for each individual damage classes. For the classification of the damage potential of an unknown accelerogram, first its fuzzy description is to be calculated, using the same sub-regions as in the training phase. It follows the comparison with the fuzzy models of the individual damage classes. Finally, an appropriate maximum fuzzy membership parameter indicates the association degree for each damage class.

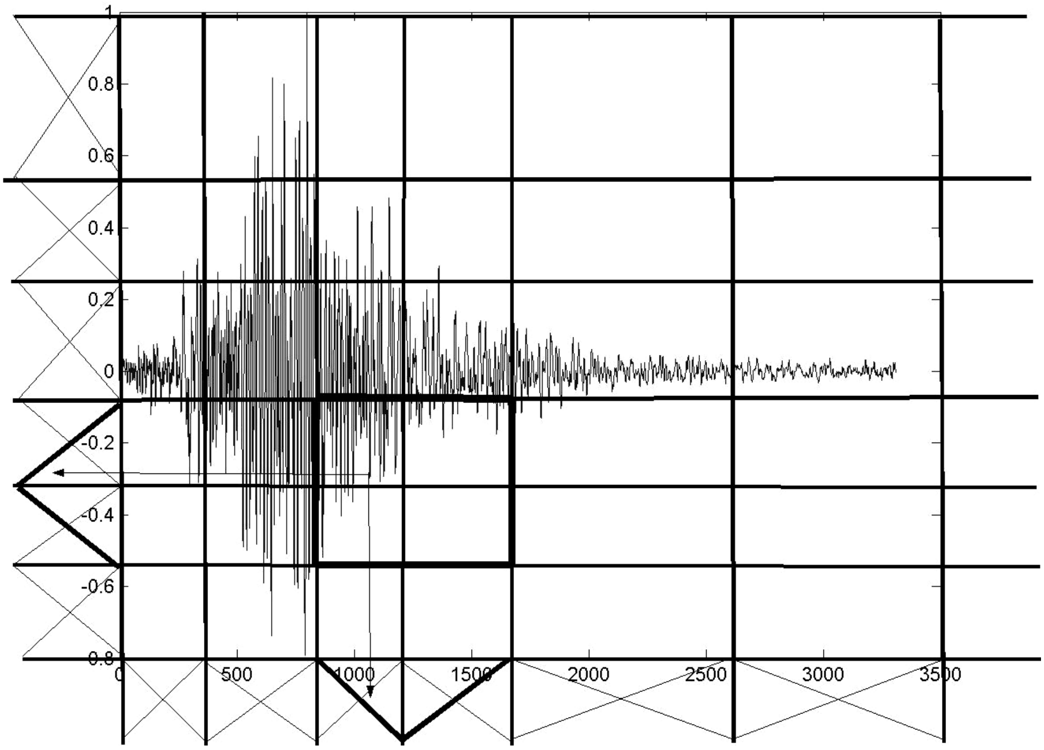

Figure 2. Sub-regions of a scaled accelerograms

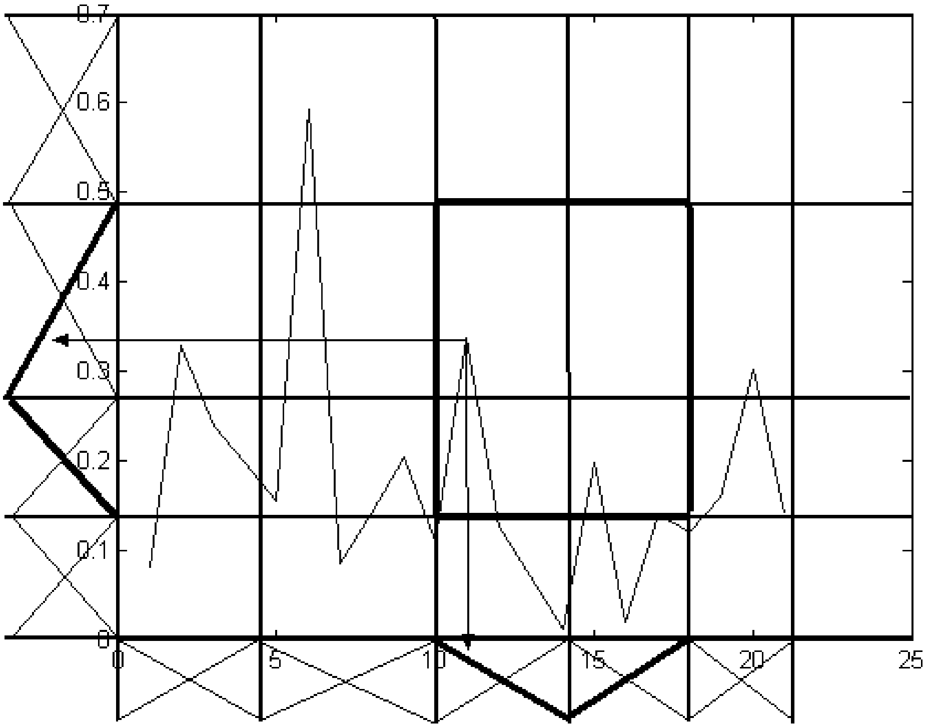

Figure 3. Sub-regions of a scaled parameter diagram

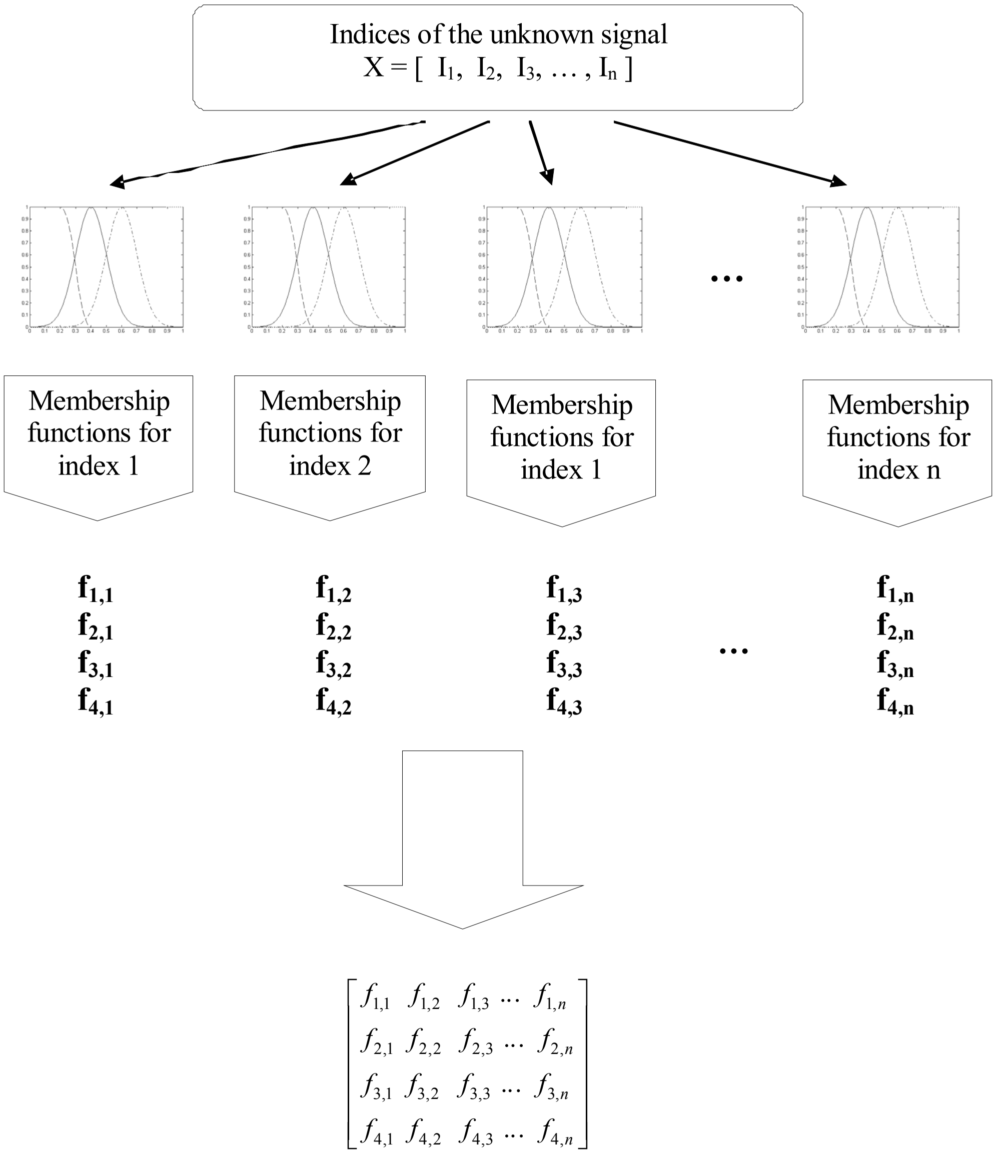

Figure 4. The fuzzyfication process

In the second technique the accelerogram is replaced by its intensity parameter diagram, which is substantially smoother (Fig. 3). The seismic parameters are the basis of this technique and have been previously computed. The selection of suitable seismic parameters took place in advance via a correlation study. In the present work 20 parameters are considered, as they were presented in section 2. The processing of the parameter diagram follows the procedure like it was introduced in the first fuzzy technique [Lazzerini and Marcelloni, 2001. In the third technique the fuzzyfication of the intensity parameters takes place via suitable membership functions, which represent the fuzzy amounts of the damage classes. Their positions are based on a training amount of accelerograms with well-known damage potential. Each parameter is connected with a membership function per fuzzy set, which expresses the similarity to the specific set and thus, to the corresponding damage class. The membership curves are chosen to be Gauss functions. Finally, the average value of the membership functions for each individual damage class is calculated. Their maximum value indicates the class to which the accelerogram belongs [Jozwik, 1983]. All intensity parameters presented in section 2 are used in this technique. Figure 4 presents the fuzzyfication process of the third method.

6. RESULTS

The accomplished nonlinear dynamic analysis supplies the system response for all 400 used accelerograms. The calculated global damage indicator MISDR, can be classified now in damage classes for each considered excitation. The limiting values, for the classification of the individual damage classes, are to be removed out of the Table 1. After the classification in 4 damage classes (low (1), medium (2), large (3) and total (4)), the training process for all three presented techniques follows. The quality assessment of the models resulted from the training process, takes place via a renewed application of the 400 accelerograms. The results, which come from the application of the three fuzzy techniques, are to be compared with those from the nonlinear dynamic analyses. The percent value of correct classification is a measure of the quality of the applied technique.

The numerical results with the application of the first technique proved that this method is not suitable for the effective evaluation of the seismic damage potential. This is to be due to the random character of the seismic accelerograms. Their application resulted in a correct classification rate of 38 %, both for the structural and also for the architectural damage. By application of the second technique the disadvantages first are to a large extent eliminated by the smoother pattern of the representative intensity parameter diagram. Therefore, the correct classification rate is substantially better than in the first technique. The correct classification rates are in this case 79.5 % for the structural and 77 % for the architectural damage indicators. Table 4 shows the results in the detail. The lines of the Tables indicate the number of accelerograms, belonging to a specific damage class (low, medium, large and total). Their intersection with the columns, point out the number of accelerograms which are assigned to a certain damage class with application of the fuzzy technique. The bold values in the diagonal indicate the number of correctly classified accelerograms. So it is to take out e.g. from the Table 4 and for structural damage that 218 accelerograms were correctly classified to the damage class 1 (low). Moreover, 11, 0 and 28 accelerograms were assigned to the damage classes 2 (medium), 3 (large) and 4 (total), although these, belong to damage class 1 after conducting nonlinear dynamic analyses.

Table 4. Classification of structural and architectural damages according method 2

Damage classes		**Structural damages**				**Architectural damages**			
		1	**2**	**3**	**4**	**1**	**2**	**3**	**4**
		Low	**Medium**	**Large**	**Total**	**Low**	**Medium**	**Large**	**Total**
1	**Low**	**218**	11	0	28	**192**	25	37	3
2	**Medium**	8	**83**	2	5	6	**60**	10	5
3	**Large**	1	21	**10**	2	0	0	**30**	0
4	**Total**	0	0	4	**7**	1	1	4	**26**
		Correct classification: 79.5 %				Correct classification: 77 %			

Table 5 presents the classification results of the third fuzzy technique. From the results it is evidently that the correct classification rate for the structural damage is 84 % and for the architectural damage is 82 %. The numerical results show that fuzzy techniques for the classification of the seismic damage potential can be used success-promising. From the three presented techniques the procedure using the fuzzyfication of the intensity parameters (third method) provided the best results.

Table 5. Classification of structural and architectural damages according method 3

Damage classes		**Structural damages**				**Architectural damages**			
		1	**2**	**3**	**4**	**1**	**2**	**3**	**4**
		Low	**Medium**	**Large**	**Total**	**Low**	**Medium**	**Large**	**Total**
1	**Low**	**234**	21	1	1	**223**	32	1	1
2	**Medium**	10	**76**	9	3	8	**64**	8	1
3	**Large**	2	12	**16**	4	0	6	**21**	3
4	**Total**	0	0	1	**10**	2	4	6	**20**
		Correct classification: 84 %				Correct classification: 82 %			

An additional index for the classification quality of each method is the sum of the product of the number of incorrect classified cases times the Euclidian distance between the correct damage classes and the incorrect predicted. Thus, for the second proposed method this product sum is equal 144 and 143 for structural and architectural damages, respectively. While, for the third method these values are equal 72 and 84, respectively.

7. CONCLUSIONS

This work presents three fuzzy techniques for the classification of the damage potential of seismic accelerograms. The first method uses a pattern recognition algorithm for the classification of the accelerograms in four damage classes (low, medium, large and total). With the second technique its intensity parameter diagram is used instead of the seismic time acceleration diagram. The seismic intensity parameters have been previously computed. Then, the pattern recognition algorithm of the first technique is adapted. Twenty seismic intensity parameters are used in the calculation. In the third technique the fuzzyfication of the intensity parameters takes place via suitable membership functions, which represent the fuzzy sets of the damage classes. The three presented techniques are applied to an eight-story reinforced concrete frame. This is designed according to the rules of the Eurocodes 2 and 8. For the nonlinear dynamic calculations 400 natural accelerograms were used. The maximum inter-story drift ratio served as global indicator for the structural and architectural damages. The results show an error rate up to 62 % in the damage classification using the first technique, from which it is evident that this technique is not suitable. On the other hand, the rates of the correct damage classification of the second technique are 79.5 % and 77 % for the structural and architectural damage indicators, respectively. Finally, the third technique provided the best results. The correct classification rates were here 84 % and 82 % for the structural and architectural damage indices, respectively.

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