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VULNERABILITY-DAMAGE CORRELATIONS IN MASONRY BUILDING SAMPLES AFTER RECENT ITALIAN EARTHQUAKES

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SUMMARY

This survey carries on previous researches about damage-vulnerability correlations; the Authors calculate corrected weights, affecting vulnerability index determination, by means of methods and statistical analyses. The study describes as well an attempt to reduce vulnerability parameters.

FOREWARD

Researches aiming to controlling and making more accurate rating of building seismic vulnerability have been lately carried out so as to attain a correct forecast of seismic hazard. To this purpose correlations between assessed damages after earthquakes and estimated vulnerability indexes have been examined.

The Authors, carrying on previous surveys on masonry buildings (Refs. 1,2), have studied three samples of areas hit by earthquakes of different intensity, and more precisely: a) sample No. 1: San Gregorio Magno Municipality (Reg. Lucania), hit by an VIII MKS on 23.11.1980; b) sample No. 2: Barrea Municipality (Reg. Abruzzi), hit by a VII MKS on 7-11.5.1984; c) sample No. 3: Opi Municipality (Reg. Abruzzi), hit by a VI MKS on 7-11.5.1984. These samples (first of which had already been examined with different techniques in above said previous surveys by same Authors, while the other two are subject of another analysis by C. Gavarini in this Conference (Ref. 3)), have been accurately examined by means of statistical analysis methods, aiming to assessing and eventually correcting the vulnerability scale proposed by Benedetti-Petrini (Ref. 4). According to this proposal, reported in detail also in Ref. 1, ten parameters considered influential on vulnerability (masonry condition, regularity of building plan, etc.), each of them affected by a "weight" according to its importance, have been examined. Furthermore each parameter is assigned a score to be chosen among three values (5, 25,

45) on the basis of its particular situation (i.e. masonry condition good= 5, bad= 45). Obviously the weights of each parameter are constant, while the score varies according to the actual condition. The sum of the scores multipled by relevant weights gives the vulnerability index.

Accomplished surveys, hereafter reported, intended to attain the following: a) a better correlation by changing the weights shown in the original Benedetti-Petrini vulnerability scale; b) an analysis of the possibilities to group parameters defining vulnerability index, so as to reduce their number.

SAMPLE DESCRIPTION AND LEVEL DEFINITION

Examined samples refer to following number of buildings: a) sample No. 1: No. 61 buildings; b) sample No. 2: No. 116 buildings; c) sample No. 3: No. 80 buildings. Vulnerability indexes have been estimated for above buildings, by means of Benedetti-Petrini scale, however limiting to eight the ten provided parameters, because the remaining two (actual condition and building particulars) have been considered not very reliable as regards evaluation.

It stands to reason that, as far as this study is concerned, damage assessment has a great importance, because an incorrect assessment should make useless every research of correlation. In this regards we are referring to mechanical damage, leaving out of consideration economic evaluation.

The definition of damage index applied in this survey (ranging from 0 to 1) is given by the following relation:

$$D = 0.06 \times Imax + 0.54 \times I \times H$$

where Imax is the maximal damage intensity with values ranging from 1 to 3, I is the mean intensity on damaged elements, and H the damage extension, that is the ratio of the number of damaged structural elements to the total number of elements. The Authors have already used this relation in the past, apart from limited changes.

Histograms in Fig. 1, showing a sufficiently regular distribution, represent the damage and vulnerability frequency pointed out in observed samples. The study of the histograms relevant to damage stresses the different intensity of the earthquakes in the three areas, thus enhancing the assessed damage definition.

INITIAL REGRESSION LINES OF SAMPLE

Fig. 2 shows regression lines relevant to above described samples, as for vulnerability values obtained by means of Benedetti-Petrini scale with original weights. Sectioning points out confidence intervals.

Minor slope of lines referring to samples No. 2 and 3 compared with that of sample No. 1, relevant to a much more intense earthquake, can be easily observed.

Correlation coefficients of samples, without weight corrections, are respectively 0.764, 0.286, and 0.492. It will be tried to ameliorate those indexes, second of them proves to be particularly low, by means of methodology hereafter reported.

VULNERABILITY INDEX CORRECTION

Correction of weights applied to vulnerability parameters so as to improve correlation to damage has been attained as follows:

Simple linear regression results in a damage-vulnerability relation, such as:

$$D = a + bV \qquad (1)$$

where $V = V1 + V2 + \ldots + V8 = K1 \times v1 + K2 \times v2 + \ldots K8 \times v8$, being Vi the vulnerability part due to ith parameter, Ki the parameter weight and vi its score. Thus it can be asserted:

$$D = a + b \times K1 \times v1 + b \times K2 \times v2 + \ldots \qquad (2)$$

Operating a multiple regression, we obtain following relation:

$$D = A + B1 \times V1 + B2 \times V2 + \ldots = A + B1 \times K1 \times v1 + B2 \times K2 \times v2 + \ldots \qquad (3)$$

Comparing (2) with (3), it can be noticed that the two relations are similar, when $Ki' = Ki \times b/Bi$ is placed in (3) instead of Ki. An iterative procedure can hence be started: Once Ki' have been calculated as above specified, new Vi' vulnerability values are reckoned. From these, by means of a linear regression, new b' value of b and by means of a multiple regression new Bi' values of Bi are calculated. The same goes for $Ki'' = Ki' \times b'/Bi'$ and so on. Once convergence is obtained, obviously there will be also $a = A$.

Weight values of three samples, corrected as above specified, are shown in Table 1. Comparing the three series of values, the single series, defined with K, is obtained, while the original series has been defined with Ko.

Sample	OSV	NSV	PEF	DER	REP	REE	ORZ	COP
No.1	3.250	0.830	0.229	0.867	0.467	0.290	0.581	1.375
No.2	1.890	0.845	0.439	0.259	0.193	1.034	3.600	1.018
No.3	0.820	0.509	0.928	0.707	1.198	1.627	1.808	1.243
Ko	1.0	0.25	0.75	1.50	0.50	1.00	1.00	1.00
K	1.75	0.75	0.5	0.5	0.25	0.25	2.0	1.25

where OSV = vertical structure organization, NSV = vertical structure nature, PEF = building location and foundation, DER = resistant element distribution, REP = plan regularity, REE = elevation regularity, ORZ = horizontal structures, COP = covering.

Table 1.

Applying values determined as above specified, correlations are remarkably ameliorated: a) sample No. 1: from 0.764 to 0.800, b) sample No. 2: from 0.286 to 0.336, c) sample No. 3: from 0.492 to 0.567.

New regression lines are shown in Fig. 3. They reveal, as regards less intense earthquake, the presence of a Vo threshold value as an intersection of the line with the X axis. Said threshold value should theoretically correspond to the vulnerability value below which buildings are not damaged and hence have to be excluded from sample. However in the case of sample No. 1 (VIII MKS), regression line should theoretically pass through origin.

PARAMETER REDUCTION

By means of multivaried analysis and main components determination, it has been tried to reduce to four the eight parameters, each of them is a linear combination of two of the first parameters.

By averaging coefficients relevant to all of three samples, following linear combinations have been obtained: TAU = 0.50 OSV + + 0.53 NSV (taking into account vertical structures), STR = 0.39 PEF + 0.47 DER (taking into account building location and its resistant elements), REG = 0.53 REP + 0.61 REE (taking into account elevation and plan regularity), TRA = 0.38 ORZ + 0.64 COP (taking into account horizontal structures and covering).

With those variables and taking into account K weights corrected as above specified, damage-vulnerability correlations of three samples are respectively 0.814, 0.361, 0.461, being the first two values improved, while the third one is reduced.

CONCLUSIONS

This study shows that asserted damage definition and methodolo gy applied for optimizing correlation with estimated vulnerability according to Benedetti-Petrini scale lead to acceptable results.

The possibility to reduce number of vulnerability parameters has to be mindfully considered and further on verified.

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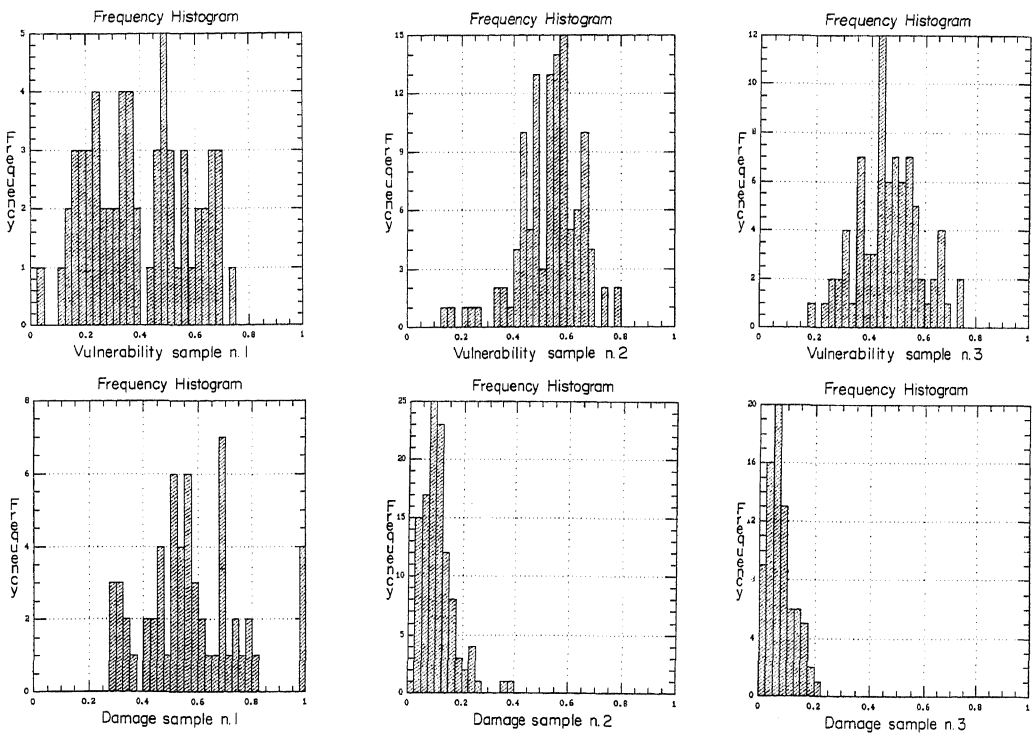

fig. 1

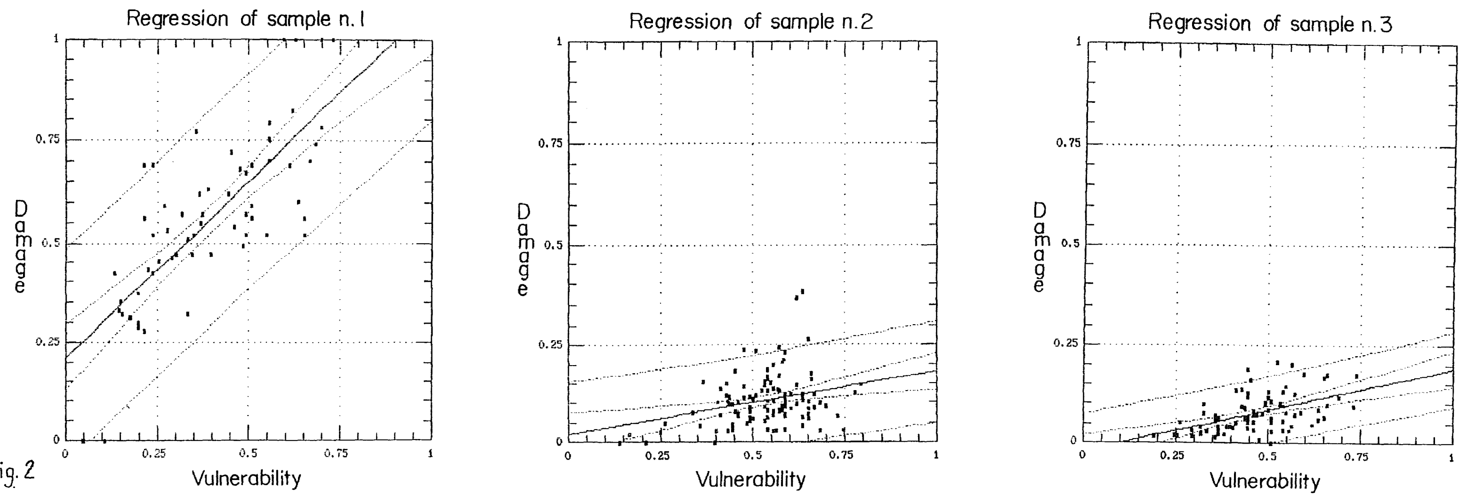
Regression of sample n.1
Regression of sample n.2
Regression of sample n.3
Damage
Vulnerability
0
0.25
0.5
0.75
1

fig. 2

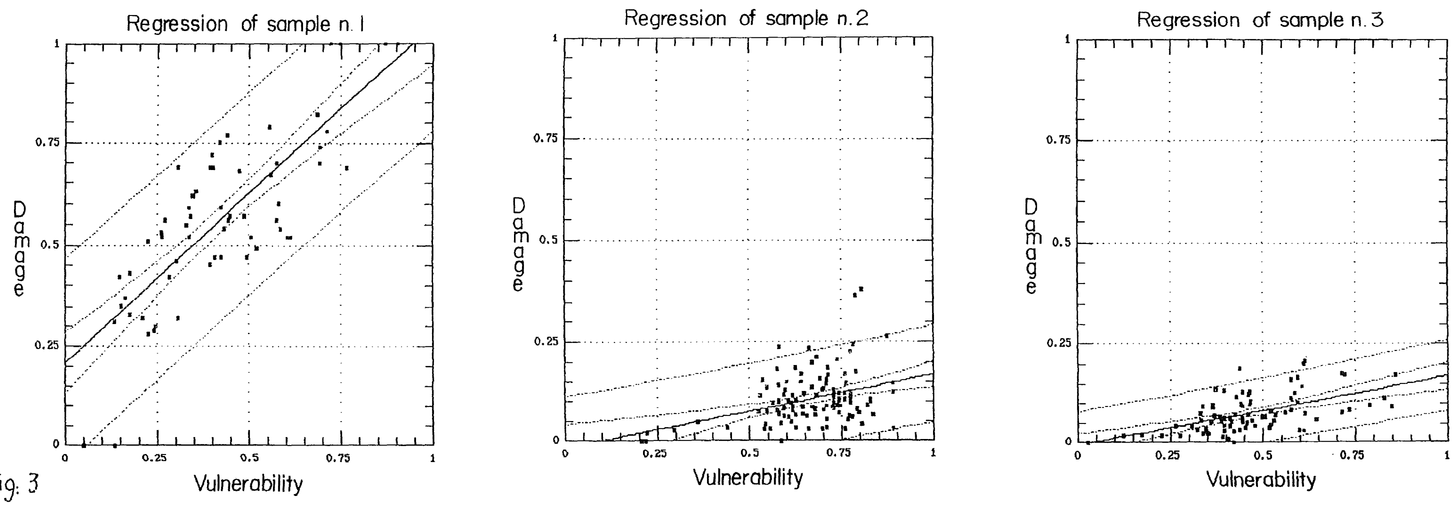
Regression of sample n.1
Regression of sample n.2
Regression of sample n.3
Damage
Vulnerability
0
0.25
0.5
0.75
1

fig. 3