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AN ATTEMPT FOR A NEW DEFINITION OF SEISMIC VULNERABILITY OF MASONRY BUILDINGS

Carlo Gavarini

Department of Structural and Geotechnical Engineering
University of Rome, Italy

SUMMARY

Presented in this paper is a proposal of a new seismic vulnerability scale for masonry buildings such that the correlation with the damage produced by earthquakes could be as good as possible. The new index is based on the same parameters presently contained in the so called second level form currently used in Italy. The proposal is tested on two samples with results which seem promising.

INTRODUCTION

It is a well known fact that once the seismic hazard of an area has been determined, the other factors that contribute to defining its seismic risk are vulnerability and occupancy. In Italy in recent years, much thought has been given to the definition of these factors, in particular to vulnerability, in the form of methodological proposals, with fields tests. The results, now fairly firmly consolidated in a survey form which provides all the data required for establishing occupancy and two possible levels of vulnerability (levels 1 and 2) and, if the building has already suffered earthquake damage, states the damage produced. This form, the use of which is illustrated in a special manual, covers both masonry buildings (according to the original proposal published in Ref. 1 with few amendments) and reinforced concrete buildings (Ref. 2), and is completed by a series of data processing models and programs that make it possible to obtain statistical parameters regarding the distribution of data collected, to derive figures concerning vulnerability, risk, cost of seismic retrofitting using different types of measures, order of priority in accordance with various criteria, and so on. The above form, in its different successive versions, has been tested in a number of surveys, conducted mainly in collaboration with the regional governments concerned. Information on the surveys is given in Ref. 3.

One of the most interesting results from the surveys is the comparison, when possible, between vulnerability and damage, since the terms of the comparison are a theoretical evaluation which is vulnerability, and a real measurable item, the damage. The comparison is not easy, however, not only because it is difficult to evaluate vulnerability - necessarily influenced by drastic simplifications and empirical assumptions - but also because the quantification of damage is not a simple straightforward procedure. We might add that there is also uncertainty as to the third dimension of the comparison, represented by the measurement of the intensity of the seismic event that has taken place; the same applies to the fourth dimension: the variability of the type of buildings damaged. It is therefore not surprising that the results are scattered, as shown, for example, in Ref. 4, where the vulnerability index is computed from the form according to the definition proposed in Ref. 1.

Improvements can be made following different ways:

- by changing the score attributed to the different parameters considered in determining the numeric value of vulnerability;
- by looking to a new scale of vulnerability, based on applying different processing methods to the initial data, without changing the information on the survey form and therefore without altering the value of the data acquired during operations carried out previously;
- by changing the approach, looking for a relationship in which the damage is directly dependent from the original parameters and intensity, without defining any vulnerability index (Ref. 5). In the present paper it is the second way which is followed.

THE NEW VULNERABILITY INDEX PROPOSED

The parameters considered in the level 2 survey are as follows: 1 - Organization of the resisting system; 2 - Quality of the resisting system; 3 - Conventional seismic resistance, c (computed as the ratio between the shear limit at the ground floor and the weight of the building); 4 - Foundations; 5 - Horizontal diaphragms; 6 - Plan configuration; 7 - Variations along height; 8 - D resisting walls; 9 - Roof; 10 - Non-structural hazards; 11 - Decay.

When compiling the survey form, each parameter is classified as A, B, C or D; A is the top class, for buildings which are seismically safe, D being the lowest. In the original proposal, each class is given points, in some cases multiplied by a coefficient to evaluate case by case. The numerical evaluation of building vulnerability is obtained by adding up the points of the eleven items.

The new proposal is based on the following observations:

1. The conventional resistance, c, should have a privileged role and have a numerical value instead of being classified in one of the four classes;
2. The other parameters should penalize the value of c, and in so doing, some of them should be related to one another.

Based on the above, the definition of vulnerability is given by the formula:

$$V = 100[1 - \prod_i \alpha i (c/0.4)^{\rho}]$$

Each coefficient αi, related to the other parameters, is smaller than or equal to 1; the value is 1 when the related parameter is attributed to Class A; hence αi is also smaller than or equal to 1. We can therefore see that V equals zero when we have $\pi\alpha i = 1$, $c = 0.4$; so that the vulnerability of a building with a conventional resistance of 0.4 and all its other parameters in Class A, is, by convention, zero. This choice is linked to the fact that such a building is considered formally antiseismic according to the code applicable to Italy's areas of highest seismic risk (1st Category).

When the other classes, B, C or D, are concerned, the coefficients α_i are defined in the following way:

- the parameters 2 and 10 are disregarded;
- for i = 4, 6, 7, 11: Class A: $\alpha_i = 1$,
  Class D: $\alpha_i = n_i$,
  Class C: $\alpha_i = \frac{1}{2}(1+n_i)$,
  Class B: $\alpha_i = 0.75 + 0.25\, n_i$;
- the values n_i are free for optimization; as a first choice, based on engineering judgment, we shall put $n_i = 0.8$ for i = 4,11 (foundations and decay) and $n_i = 0.9$ for i = 6,7 (plan configuration and variations along height), so that in the four classes we will have: i = 4,11: α_i = 1 - 0.95 - 0.9 - 0.8;
  i = 6,7 : α_i = 1 - 0.975 - 0.95 - 0.9;
- the parameters 1, 5, 8, 9 are associate jointly in a unique variable α_o, which has the role of defining the efficiency of the so called "box behaviour" of the masonry building; the proposed definition for α_o is expressed by table I, where the function $f(x_i)$ is given by:

$$f(x_i) = [x_i + (1-x_i)\beta\alpha_9]\alpha_8$$

$$x_1 = \delta, \quad x_2 = \delta + \frac{1}{3}(1-\delta)$$

$$x_3 = \delta + \frac{2}{3}(1-\delta)$$

β is the ratio of rigid and well connected floors, furnished by the survey form;
and α_8 and α_9 are related to the maximum distance between resisting walls and roof, and they are again defined by formulas (3); δ, n, are free for optimization; the first choice will be:

Tab. I

		P5			
P1	P9	A	B	C	D
A,B	A,B,C,D	1	1	1	$f(x_3)$
C	A,B,C	1	1	$f(x_3)$	$f(x_2)$
	D	1	1	$f(x_2)$	$f(x_2)$
D	A,B	1	$f(x_3)$	$f(x_2)$	$f(x_1)$
	C	1	$f(x_2)$	$f(x_2)$	$f(x_1)$
	D	1	$f(x_1)$	$f(x_1)$	$f(x_1)$

$\delta = 0.7$, $n_8 = 0.9$, $n_9 = 0.5$, and ρ is free for optimization.

THE NUMERICAL DEFINITION OF DAMAGE

The survey on damage gives, for every floor of the building: the level of the most extended damage, L; the extension of such damage, E; the level of the maximum damage, M. The level is attributed in six classes according to the type and width of the cracks. The measure of the total damage is defined as follows:

$$D = \frac{1}{N_d} \sum_{i=1}^{N_d} \{\Gamma_v[f(E_{vi})\, f(L_{vi}) + \delta_{vi}] + \Gamma_h[f(E_{hi})\, f(L_{hi}) + \delta_{hi}]\}$$

N_d is the number of floors above the ground floor (the floors under the ground are disregarded);

v,h are indexes, referred to vertical and horizontal structures;

Γ_v, Γ_h are weight coefficients, possibly free for optimization, with an initial choice of 0.6 and 0.4;

f(...), f(...), are functions defined by Fig. 1;

δ_{vi}, δ_{hi}, are contributions of the maximum damage, M:

if $M_i = L_i$: $\delta = 0$

if $M_i \geqslant L_i$:

$$\delta = \begin{cases} f[\mu(1-E_i)] * f(M_i) & \text{if } E_i \geqslant 0.5, \\ f(\mu E_i)\ f(M_i) & \text{if } E_i < 0.5, \end{cases}$$

$\mu = 0.2$

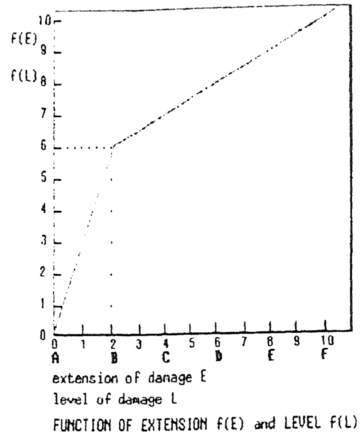

Fig. 1

THE APPLICATION TO THE SAMPLES BARREA AND OPI

BARREA is a little village of central Italy, hit by an earthquake in May 1984, VII MCS; 116 buildings in the historical center were surveyed accurately and constituted the sample for the first attempts of the new scale.

The first values given to ρ were 1 (linear scale) and 0.5 (square root), with better results for 0.5 in terms of V/D correlation coefficient, R. Then a systematic research was conducted on the influence of ρ, with the results indicated in Fig. 2, and finally the square root relationship was definitely selected.

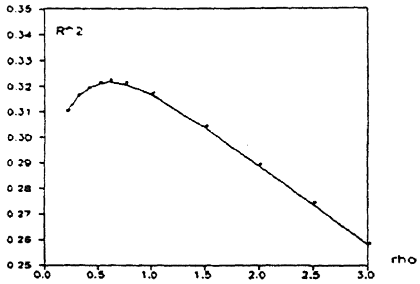

Fig. 2

Fig. 3 presents (crosses) the diagram V/D with the linear regression line: the correlation coefficient is 0.567, whereas it is 0.483 for V_0/D.

The above results present some progress in respect to the definition V_0, being based on the first choice of the different coefficients n_i, δ, Γ. Now an attempt for optimization has been performed, looking to the correlations between damage and the single parameters which define; after such research the final choice has been the following:

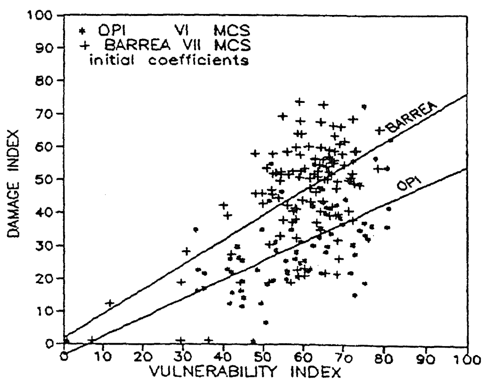

Fig. 3

$n_6, n_7, n_8, n_9, \Gamma_v, \Gamma_h$: unchanged;

$\delta = 0.6,\ n_4 = 0.86,\ n_{11} = 0.64$

Furtherly, a new parameter has been introduced, related to the total volume of the building, $\alpha 12$, with a linear variation from 1 (for volume $\leq$ 500 mc) to 0.78 (for volume > 1500 mc).

The correlation coefficient R grows from 0.567 to 0.599 just by introducing $\alpha 12$, and then to 0.628 after optimization of the other coefficients. It is also interesting to mention the values of the correlation coefficients C/D and α/D, respectively 0.458 and 0.605, after optimization.

OPI is another village, close to Barrea, where the intensity was VI MCS; here the sample comprises 81 buildings. The diagram V/D with the initial given values for the coefficients is shown in Fig. 3 (stars), together with the regression line (R = 0.549).

Now, if the parameter volume is considered, $\alpha 12$, there is practically no change in R (R = 0.547); if the optimal values of the coefficients determined on the sample Barrea are adopted the value of R grows to 0.593, and the two regression lines appear as in Fig. 4. The specific optimization conducted on this sample gave very close results, with R = 0.600.

The possibility of non linear regression was explored and finally, after some attempts, it appeared that the best choice was a linear regression in the plane $V/\sqrt{D}$, with R up to 0.680 (Barrea) and 0.636 (Opi).

Then a further large progress was obtained with the introduction of a "dummy variable": the values of R grow to 0.777 (Barrea) and 0.726 (Opi) and the comparison between the two regression curves in the plane V/D appears very satisfactory (Fig. 5), better than the curves without dummy (dashed lines).

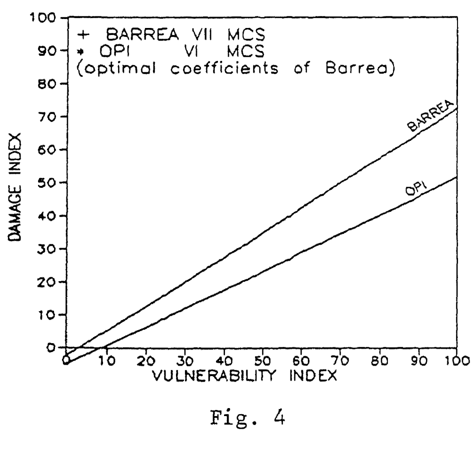

Fig. 4

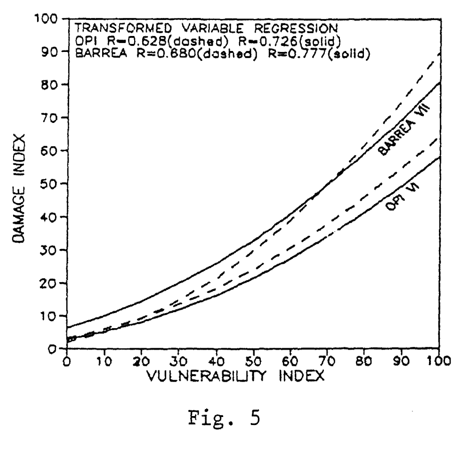

Fig. 5

CONCLUSIONS

The results obtained seem promising. Now further calculations are in progress in both the directions of:

- considering new samples, with different typological characters and/or larger intensities;

- considering multivariate regression on the original parameters, as proposed in Ref. 5.

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