ASSESSING SEISMIC VULNERABILITY IN VIEW OF DEVELOPING COST/ /BENEFIT RATIOS FOR EXISTING R.C. BUILDINGS IN ITALY

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SUMMARY

A subjective approach to assess seismic vulnerability of existing r.c. buildings on large areas is proposed. Vulnerability is defined by specifying one of three levels for twenty significant parameters as well as an information reliability degree. Thus, hazard (in terms of monetary losses or victims) can be obtained depending on expected seismic intensity through vulnerability curves. Tests have been performed by comparison with after earthquake surveys in Italy in order to correct numerical weight of parameters.

OBJECTIVES AND TYPES OF APPROACH

General plans for mitigation of seismic hazard on large areas should pass through three successive steps:
1) Seismicity maps, showing maximum seismic intensities on large areas (large scale risk) and in restricted areas (local risk by microzonation)
2) Hazard maps (in terms of monetary losses or victims), obtained by classification of buildings depending on their different vulnerability
3) Cost/benefit ratio maps, bounding areas with equal benefit/cost ratios (hazard mitigation divided by retrofitting cost necessary for).
Each step (from the first to the third one) attempts more accurate priority criteria in seismic mitigation program.
Because only few areas in Italy have no significant seismic risk and because a large variation in vulnerability is due to differences in quality, types, age of constructions, only hazard and cost/benefit ratio maps are really significant for developing priority criteria. Methods to assess vulnerability can be divided into three groups, i.e. subjective, experimental and theoretical methods.
Seismic Safety Commission of California (Ref. 1) applied a second type methodology to evaluate hazard in terms of victims LSR (life safety ratio, i.e. expected victims per 10000 inhabitants) and then cost/benefit ratios for State owned buildings. Benefit is obtained as difference between LSR and LSRG (life safety ratio goal, i.e. the minimum value of LSR for the con

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sidered class of buildings).
An example of the second type methodology with evaluation of hazard in terms of monetary losses can be found in Ref. 2, where experimental damage functions define losses for each class of buildings.
Scholl and others (Ref. 3) achieved a theoretical evaluation of hazard for single buildings, calculating interstory drift which depends on engineering intensity (EI) of expected earthquakes. Then, summing damages obtained for each component by means of damage functions (Ref. 4), an expected total damage can be calculated.

PECULIAR PROBLEMS IN ASSESSING VULNERABILITY ON ITALIAN AREAS

At the moment, the biggest problem in Italy is the lack of general experimental data, necessary for testing any methodology.
Braga and others (Ref. 5 and 6) deduced damage probability matrices from data of an after '80 earthquake survey on 38000 buildings. Unfortunately, constructions surveyed are old, low rise and of poor masonry with not sufficient presence of reinforced concrete and medium rise, of good masonry,buildings. Moreover, type of information (due to the specific objective of survey, explained in Ref. 7) does not allow a classification more accurate than Braga's one, attempting only three types of vertical structure (field, hewn stone and brick masonry) and four types of horizontal structure (vaults and wooden, steel o r.c. floors) and one class of r.c. buildings.
Typical urban configuration, especially of old towns, is a second big matter. Buildings have been frequently attached each other, with or without connections; thus, seismic performance of these long rows of buildings is really hard to define, or, say, it is hard to isolate a seismic performing unit that can be defined as the minimum one,inside the block examined.
Moreover, a large difference in materials, types of construction, which can be found out in each one of the seismic performing units, in addition to a frequent, non-engineered, or non-seismic-designed buildings (also in high risk areas), make the analysis hard to be done.
Finally, a methodology for assessing vulnerability, needs to satisfy two contrary conditions. To be feasible, it should allow a survey sufficiently fast and should not require any test in place. Otherwise, due to large differences that can be found out in details for old as well as new buildings (whether r.c. or masonry structures), it is necessary to know dimensions of resisting elements, reinforcement steel and so on, in order to evaluate the vulnerability.
Two levels methodologies have been developed in a specific research unit of G.N.D.T. (Gruppo Nazionale di Difesa dai Terremoti) of Italian Consiglio Nazionale delle Ricerche. The first one is based on Braga's results; the second one, which the present paper belongs to, is of a subjective type.

ASSESSMENT OF VULNERABILITY FOR R.C. BUILDINGS

Parameters considered

Classes of vulnerability are obtained in a subjective way, but integrated by examining analogous studies.
Nine significant groups of parameters are taken into account, as shown in the following table, each one with three possible levels from A, the best one, to C, the worst one.

Vulnerability parameters for r.c. buildings

Parameter		Level A	Level B	Level C
1.Resisting elements	1.1.Main seismic resisting system	Stiff - - strong	Stiff-brittle/ /flex.-strong	Stiff-brittle /flex.-weak
	1.2.Type of critical elements	Good	Ordinary	Poor
	1.3.Crit. elem. ductility/strength	High	Medium	Low
	1.4.Low ductility elements	Not present	Present/low ductility	Present/very low ductility
	1.5.Construction quality	Good	Ordinary	Poor
	1.6.Conventional safety ratio r	$r > 1.5$	$0.7 \leq r \leq 1.5$	$r < 0.7$
2.Foundation		Suff. bear. capacity	Insuff.cap./ /stiff connect.	Insuff.cap./ no stiff conn.
3.Diaphragms		Well fasten. and stiff	Medium fast. and stiff	Badly fasten. and stiff
4.Plan configuration		Regular	Non regular	Strongly non regular
5.Types of varying elevation	5.1. Setbacks	Not significant	Ordinary	Important
	5.2.Varying resisting system	Differ. within the level	Difference up one level	Difference over one level
	5.3.Varying diaphragm	Up to 25% worse	Within 25-50% worse	Over 50% worse
	5.4.Varying plan configuration	"	"	"
	5.5.Varying masses	Decreasing to upper fl.	Not significant	Increasing to upper floors
6.Safety of non structural elem.		Fastened	Non fastened/ /safe	Unsafe

7.Damages	7.1.On resisting elements	Not signifi-	Up to50% are cracked	Up to 50% are yelded
	7.2.On diaphragms	Not signifi-cant	Slight	Severe
	7.3.On foundation	"	"	"
	7.4.On connect. of non struct. el.	Not signifi-cant	Up to 50% are damaged	Over 50% are damaged
8.Safety of interior lines		High	Medium	Low
9.External hazards		Low	Medium	High

A more detailed definition of each level is given by a specific guide book; a summary of this book, concerning the first group of parameters, is given in the following.

Main seismic resisting system

Seismic performance of existing r.c. buildings is evaluated taking into account infilled masonry walls (except not completed constructions or limited parts of the buildings like a soft story). Thus, r.c. walls or r.c. frames with infilled well featured masonry walls, are classified on A level (i.e. constructions keeping theirselves stiff and strong during earthquakes). Constructions of B level have an initial good and stiff, but brittle (due to weak infilled masonry walls), behavior. Then, the sole resisting elements are r.c. frames; however, they must be sufficiently strong and ductile. Constructions of C level have the same initial behavior of B level, but r.c. good frames are missing.
In uncertain situations, the level assessment is performed with regard to the main seismic resisting system, i.e. that one which can carry over the 70% of seismic actions.

Type of connections and critical elements/ Connections and critical elements strength and ductility

For the importance of connections and seismic critical elements, and for the frequent lack of information in reinforcement steel, dimensions, the parameter no. 1.2. (see table) takes into account what is easy to find out by simply looking at, or measuring, the elements; on the contrary, the parameter no. 1.3. (see table) takes into account what is hard to find out without tests in place (it means data might be assumed by drawings or other type of sources associated with a poor level of information reliability).

Low ductility elements

Low ductility elements, like short columns or walls, are considered as increasing vulnerability for their simple presence.

Construction quality

This parameter includes, not just materials quality, but also construction and design types, which are of great importance, especially in non-engineered buildings and in areas where technicians and constructors are not aware of seismic risk and are used to doing buildings which cannot carry neither seismic actions nor a minimum of horizontal forces. That frequent situation can be found out in areas where laws have not forced to consider seismic actions and where people have forgotten or never experienced earthquakes.

Conventional safety ratio

A simple calculation of ratio between a conventional seismic force assumed as $0.4 \cdot R \cdot W$ (where R is the value of response spectrum for building period and type of ground into consideration, and W is the total weight of the building) and the sum of resisting shear forces offered by infilled masonry walls, r.c. walls and columns is performed, in order to evaluate, in a simplified manner, the total amount of seismic resisting vertical elements.

Vulnerability functions

Curves, like those shown in figure, was assumed for defining vulnerability (in terms of monetary losses - first group of curves - or victims - - second group of curves -).

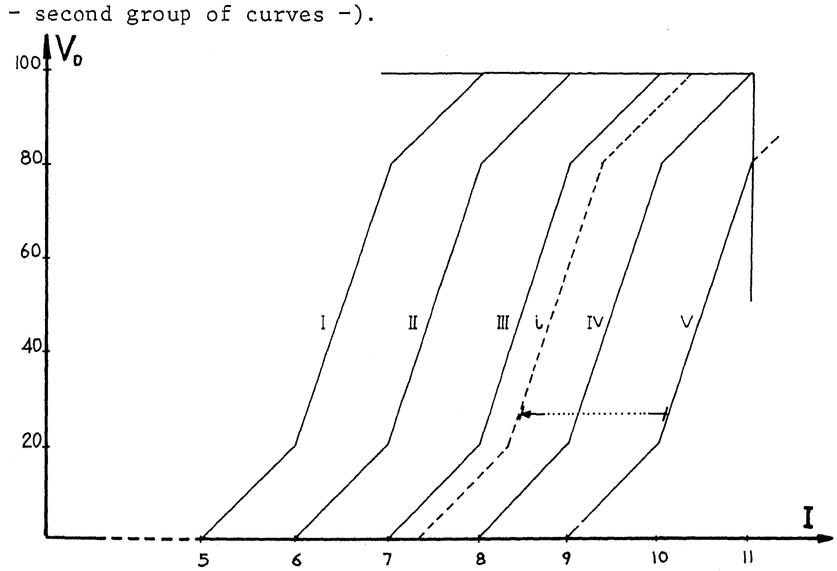

Fig: V_D is the percentage ratio (monetary cost of repair to previous conditions)/(actual value of the building) (uncorrected V_D-curves)

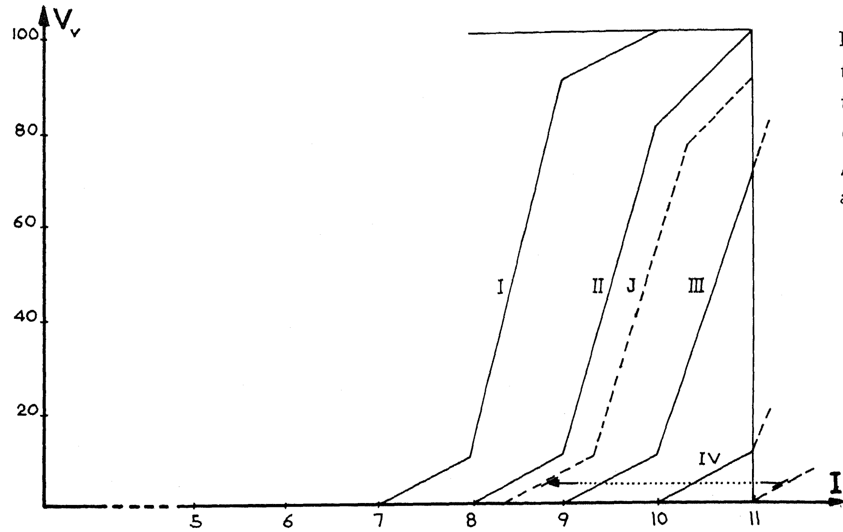

Fig: V_v is the percentage ratio (deaths)/ /(inhabitants)

The total sum of penalties (or exceptionally premia) corresponding to different parameter levels, defines, if measured on the horizontal axis -starting from V curve in figure-, the exact position of the curve representing the vulnerability for a building considered (i-curve in figure). Thus, an average hazard value can be calculated for each intensity level. Now, it is necessary to discuss the reliability of values obtained.

As a first, each value is an average one, with scattering bounds determined by a weighted mean of information reliability degrees corresponding levels. As a second, due to the characteristics of a second level method of assessing vulnerability, results reliability is restricted to samples having a great number of buildings. In the other hand, results for single buildings or for few buildings samples could be wrong.

FIRST TEST RESULTS

A first test was performed on a 40 r.c. buildings sample in a small, close-to-Rome town(') with medium seismic risk, but only recently included by law in seismic areas.

Two groups of results were looked for:

1) Feasibility of the field survey and time required for
2) Field evaluation of penalties (or premia)

No difficulties were found and the average time necessary for surveying one building was evaluated 1^h 45' with a maximum of 2^h 15'. Moreover, hazard calculated for the maximum actual seismic intensity in the area, matched subjective fielf evaluations. Finally, the low importance of two parameters (no more appearing in table), became evident.

(') Town is Gennazzano and the survey was done by T. Ricci, eng. student.

SECOND TEST RESULTS

A more important second test has been performed on about 100 r.c. buildings[1] struck by earthquakes. The main goal of the second test has been a comparison of theoretical results and monetary losses surveyed and, eventually, a correction of the numerical importance for each parameter.
A range from VI to IX seismic intensity was examined and theoretical and experimental values are shown in figure.

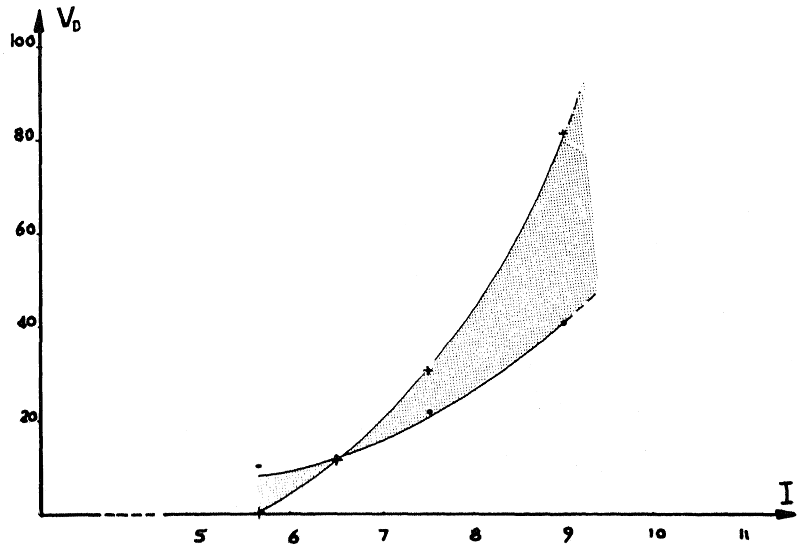

Fig: Theoretical (-+- line) and experimental (-o- line) for V_D values

Scattering results show a good agreement on VI and VII intensity level, but theoretical values higher than experimental over VII level. Three possibilities could have be done:

1) Seismic intensity level is not well evaluated
2) Vulnerability curves at high levels of intensity are lower than those assumed
3) Numerical importance (penalties or premia) of parameters has to be changed

It was impossible, at actual state of art in macroseismic studies, to examine the first consideration.
A separate analyisis was done to evaluate the importance for each parameter;

(1) The sample is subdivided as following: 10 buildings are obtained from Friuli '76 earthquake; 50 buildings from an after Irpinia '80 earthquake survey (GEORIPAD) conducted by Istituto di Scienza delle Costruzioni, Facoltà di Ingegneria (Rome); 40 buildings were recently surveyed by T. Ricci in areas hit by Irpinia '80 earthquake.

as a consequence, penalties (or premia) have been varied depending on their contribution to total theoretical values, as well as vulnerability curves at high levels (in terms of monetary losses) have been changed as shown in fig.

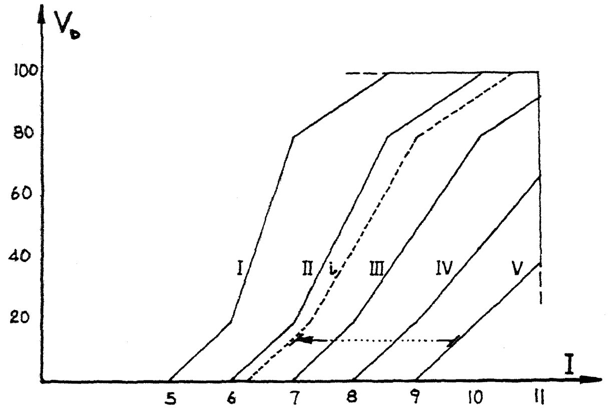

Fig. Corrected V_D-curves according to second test experimental results.

Such a behavior satisfies a general condition, well known for structures: for ductile, strong and good performing r.c. buildings (like those represented at right side), losses do not increase as quickly as shown by functions at left side of the figure.

CONCLUSIONS

A first step for defining priority criteria of seismic retrofitting on large areas is attempted by means a subjective methodology (tested by experimental results) for assessing vulnerability of r.c. buildings. First tests have partially corrected the numerical importance of parameters considered, and we expect further corrections through future tests.
Methodology criteria and parameters have been assumed for evaluating hazard in r.c. buildings that a specific Committee is examining at Pozzuoli (near Naples) exposed to brayseism risk.

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