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Ten years of research into the seismic vulnerability of constructions in Italy

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Abstract
The lines of research into the seismic vulnerability of constructions in Italy since the November 23, 1980 earthquake are set out.
Information is offered about the place of Italian research in relation to the international framework, the activities of GNDT, the initiatives for risk limitation developed by Public Authorities, the subsequent seismic events.
The treatise concludes by indicating the possible directions for future development which seem particularly important at the present time.

1. Premise

The earthquake that struck vast areas of Southern Italy on November 23, 1980 gave further confirmation of the great influence that the vulnerability of works built by man has on the seismic risk of the Italian regions.

Ten years after the event many questions about this vulnerability are justified, but one in particular involves the scientific world, namely how knowledge has been increased.

The examination of Italian research over this decade, which is the object of this work, can contribute towards an answer. It can also be used to examine international research seen from one particular aspect, *i.e.* through its reflection in a specific Mediterranean country.

The bibliography which concludes this paper is intentionally limited to the works written in Italy between 1980 and 1990 and has the aim of giving a sufficient, though not complete, representation of this period.

2. Elements of chronicle

Data about the seismic vulnerability of constructions in different Italian regions were already present in very antique chronicles in which the description of the damage caused by earthquakes was often accompanied by summary comments and information on what had been damaged or destroyed.

A more recent documentation is composed of many expert examinations, now preserved in historical archives, carried out on various types of constructions to decide on the amount of economic loss after earthquakes occurred in this century or in the preceding ones.

Also on-site observations by seismologists such as Mercalli, while directed towards the estimates of macroseismic intensity, intrinsically implied a reading of the connection between damage and vulnerability.

This is a question of extremely interesting cognitive sources which are now being studied to obtain precious information about the architectonic heritage of urban nuclei; but obviously these sources are outside the framework of organic approaches to the vulnerability theme.

Only in very recent times, *i.e.* in the second half of the Seventies, were systematic examinations of damage started: after the Friuli earthquake elaborations on the regional and urban

scale were carried out on data gathered for other purposes and relations between the extent of the damage observed and certain characteristics of the buildings came to light.

Generally speaking one may judge the attention paid by Italian researchers before 1980 to the subject we are discussing as largely insufficient. Prior to 1980, most of the studies were not expressly calibrated on the Italian reality or directed toward the observation of actual damage, but instead focused on probabilistic forecasts of the damage associated with the occurrence of specific earthquakes, which is the true essence of the vulnerability assessment. This circumstance should be criticized. All this arose in an international context in which there were already important treatises on this subject.

The most immediate consequence of the Irpinia earthquake, however, was really not in the field of forecasting but in that of the observation of the damage. The seriousness of the event and the large number of settlements affected made clear to the relative Ministries the chance of having information about the situation in which the buildings found themselves, to give rational support to the decisions to be taken after the catastrophe. Researchers operating in the National Geodynamics Project (PFG) collaborated in the definition of the form for the gathering of data on-site and drew it up so that it contained useful information not only regarding the emergency but also to reveal any recurring relations between damage and structural characteristics (Gavarini, 1981). The form thus offered, apart from the quantification of the damage, also the knowledge, over about 40 000 habitation units, concerning the dimensions, the history, the typology of the horizontal and vertical structures of the building, *i.e.* the elements that had seemed more significant in other investigations previously carried out in other countries. It was an important moment because it signalized, in Italy, the beginning of the acquisition of a data base on constructions and their behaviour during earthquakes through surveys directed expressly to vulnerability.

This was immediately followed at the beginning of the Eighties by the introduction of original methodologies for the formalization of this vulnerability, which were then experimented in the field with some amplitude. They were inserted into two of the three conceptual lines that were prevalent at that moment and are still widely used in the ambit of this discipline (Corsanego, 1985).

The first line (typological), fairly widespread in the world, is based on the conception of the building as an element of a class or typology defined in terms of the materials, the construction technologies or other factors, whose behaviour can be expressed probabilistically by means of the statistical processing of data about damage caused by real earthquakes. The second (mechanistic), followed above all in geographical areas with a prevalence of buildings with quite clear structural schemes, is founded instead on the probabilistic assessment of the seismic response of a theoretical mechanical model of the building. The third (hybrid), which has its origins in some techniques applied in the United States in the Sixties, tends to combine the quantitative with the qualitative information on the building using various procedures.

A method introduced by Braga *et al.* (1982) comes into the first line. It could be called the first concretely usable procedure for the estimate of vulnerability on wide scale in Italy. Concentrating on the typologies observerd after the 1980 earthquake, thirteen classes of building were constituted and to each class was associated, on statistical bases, the probability of undergoing certain types of damage in correspondence with different degrees of intensity.

The methodologies of Benedetti and Petrini (1984) for masonry buildings and of Gavarini and Angeletti (1984) for reinforced concrete structures come into the third line. Even though they are independent of each other and different in various aspects, they have in common the conceptual and operative support. Both in fact are based on the definition of a certain number of behaviour factors, for example the general organization of the resistant system, the efficiency of the connections, the morphological regularity, the seismic capacity and so on, on the giving of a partial mark to the building for each factor on the basis of quantitive and qualitative evaluations, on the determination of a global vulnerability index in terms of the partial marks. It must be emphasized that when these hybrid methods ap-

peared they did not clearly possess a significant support of statistical investigation that would make it possible, given a certain vulnerability index, to specifiy probabilistic relations between intensity and damage. Thus they gave, for some time, by means of the index, only a conventional representation of vulnerability, which, filtered through expert judgement, was widely used for relative comparisons and calculations.

In the meantime, in 1981, the "National Group for the Earthquake Loss Reduction" (GNDT) was formed, which gave great importance to the problems of the existing constructions. It assumed, for the assessments of vulnerability, an operative approach destined to characterize most of the activities in this field in Italy in the following years, *i.e.* the introduction of several possible levels on which to carry out assessments (Gavarini *et al.*, 1984). The articulation on several levels, which corresponded to analogous «multiple screening strategies» experimented in the United States, was aimed at making possible, case by case, a choice between several techniques, which with increasing complexity would accompany an improving quality of data acquired. Two levels were adopted, associated with the methodologies described above. The typological one, simpler but essentially limited to large sets of buildings, was assigned to the first level, while the hybrid ones, more elaborate but more adapted — at least potentially — also to single constructions, were assigned to the second.

The bradyseismic phenomena at Pozzuoli offered, half-way through the Eighties, an efficient operative test bench (Giangreco, 1984). The contingent problem was that of supplying an objective reference point, in terms of vulnerability, to the decisions on the usability of the damaged buildings and on the upgrading operations to undertake. A group of experts was then consulted who based their judgement on a vulnerability index obtained with a hybrid methodology similar to those mentioned above (Benedetti *et al.*, 1984).

The application made on the Pozzuoli site and the comparison between index values and observed bradyseismic damage (Ramasco, 1985) can be considered the first calibration — even if limited to only one seismic intensity — of techniques based on vulnerability indices, to be made in Italy.

Still around the mid-Eighties, there was a series of operations in Italy promoted by local Administrations, which made it possible to test the above methods repeatedly. Among the activities which involved GNDT we recall those in Emilia Romagna (Regione Emilia Romagna and GNDT, 1984) and in Tuscany (Regione Toscana and GNDT, 1986). Among the others there was an investigation in Umbria in the urban nucleus of Gubbio (Benedetti *et al.*, 1988), where the hybrid method of Benedetti and Petrini was applied to cost-benefit analyses and to the comparison between different upgrading strategies.

These operations, which were followed by others, even if they concerned a limited part of the country, had a notable cultural significance because for the first time in Italy some Public Administrations turned their attention to the vulnerability of their territory not after but before the earthquakes, as in other parts of the world they had been doing for some time.

This new attention had its effect in the research field motivating studies for the construction of dynamic maps of vulnerability (Augusti and Borri, 1986) directly aimed at urban planning and, successively, for computerized systems having analogous intentions (Zuccaro, 1989). The continuation of this line has also brought about other recent studies on the optimal allocation of resources in seismic areas by means of dynamic programming (Augusti *et al.*,1989).

Some seismic events (in Parma, 1983; in Central Italy, 1984) supplied elements for the calibration of the procedures of the first and second levels. For those of the first level the already existent data base was increased and gave substantial confirmation of the relations between seismic intensity and damage which had already been proposed (Braga *et al.*, 1986b). For those of the second it was possible to introduce, thanks to the observed behaviour, analogous intensity — damage or acceleration — damage relations in terms of the vulnerability indices and to offer therefore, using these indices, representations of vulnerability which were no longer only conventional but which could be inserted in the classic probabilistic risk assessments (Petrini, 1988). Other calibrations were made, reconstructing *a posteriori* the vulnerability of buildings damaged by the Friuli earthquake, on the

basis of archive documents (Benedetti and Benzoni, 1985).

It must be remembered that, during the same years, other methodologies were elaborated by Italian researchers, which, while less widely used than those above, expressed approaches deriving from different lines of thought or were the counterpart, in Italy, of expanding investigation techniques abroad.

One of these approaches referred to the mechanistic line already mentioned, which is the most closely connected with structural mechanics and which had a vast range of applications in countries like the United States and Japan but was limited in Italy by the prevailing attention paid to the vulnerability of urban nuclei characterized by construction morphologies often a long way from present engineering schemes. However there was no lack of studies of this kind on Italian towns: a probabilistic methodology based on mechanical modelling was applied to the reinforced concrete buildings of Subiaco (Nuti *et al.*, 1987).

Another approach, belonging to the hybrid line, concerned the use of theories such as fuzzy sets to represent suitably the qualitative components, typical of expert judgements. On the international scale, in the Eighties, the fuzzy set theory was finalized many times towards the assessment of vulnerability above all by American and Chinese authors. In Italy, the first proposal for its use was in 1984 (Corsanego, 1984); systematic studies were made by researchers of the University of Padua (Bernardini and Modena, 1986), in the context of investigations into the vulnerability of the buildings in the Veneto area, which began in preceding years (Zaupa *et al.*, 1982). An application proposition of the evidence theory followed the same conceptual line (Corsanego *et al.*, 1986).

A third approach can be considered as extreme in the ambit of the hybrid line in that it is almost exlusively based on the qualitative components. It was developed by Giuffré *et al.* (1988) with reference to ancient Italian urban nuclei. Its essential feature consists of an individualized examination of the buildings in which, instead of rendering explicit probabilities of damage and collapse, investigation is carried out about the potential mechanisms in accordance with which damage and collapse could occur.

In the same years again works were published dedicated to the so-called secondary vulnerability, *i.e.* the seriousness of the socioeconomic consequences caused by a hypothesized seismic damage to the buildings; secondary vulnerability is a research sector in which there are great uncertainties and in which information coming from different parts of the world is to be used with caution because the impact of the same damage can change very much from one country to another. The assessments made concerned above all the direct economic losses (Angeletti, 1984; Angeletti and Petrini, 1987) which are a consequence of the damage which is traditionally the basis of many cost-benefit analyses; other kinds of consequence were dealt with on the methodological level (Corsanego and Del Grosso, 1989).

In the second half of the Eighties there was a moment for rethinking and reflection in Italy about the whole problem of vulnerability which was motivated by what was learnt from the concrete application of the methodologies, from critical comparisons between first- and second-level methodologies (Braga *et al.*, 1986a, 1987b), from discussions between specialists (Augusti, 1987) which all gave new impulses to research.

As for the methodologies officially adopted by GNDT, the typological one was subjected to experiments designed to test its adherence to the different local urban nucleus situations (Corsanego *et al.*, 1990). The hybrid methodology concerning masonry buildings was re-examined to obtain better agreement between theoretical vulnerability and observed damage (Gavarini, 1988; Angeletti *et al.*, 1988; Cherubini and Zingali, 1988; Guagenti and Petrini, 1989). The methodology concerning reinforced concrete buildings was modified much more radically by researchers of the Universities of Rome and Pisa (Gavarini *et al.*, 1990; Beconcini *et al.*, 1990); a completely new version was elaborated for it in which the mechanical modelling, obtained by means of *ad hoc* calculation codes which, among their other characteristics had that of taking into account the collaboration between reinforced concrete frames and masonry walls (which in certain situations was decisive for the survival of the building in the Irpinia earthquake), took on an important role. A parallelism between the approaches to masonry and reinforced concrete,

which was instead fairly transparent and intentional in preceding experiments (Regione Emilia Romagna and GNDT, 1984) was thus, equally intentionally, allowed to fall aside.

A very acute consequence of the reflection concerned the conceptual and operational separation between the systematic acquisition of data about vulnerable organisms and the evaluation of their vulnerability. In effect, on the conceptual plane, data acquisition is a cognitive moment while vulnerability assessment adheres to the forecast sphere; operatively, the acquisition of data, which is delicate, expensive and difficult to repeat, must be offered in a way that can be used for most of the vulnerability methodologies, present or future. All this was confirmed in new on-site survey forms (GNDT, 1989) which, differently from those before, no longer made explicit reference to specific methodologies. With this separation the expressions «first level» and «second level» or those concerning higher levels, took on a new meaning, no longer referring to the methodologies but to the completeness of the data.

The end of the Eighties marked an opening towards the procedures that adhere more directly to the discipline area of artificial intelligence and which have an important operative tool into expert systems. Also, in this case, what happened in Italy reflected what was happening in the vulnerability field in other parts of the world. This field effectively, because of the mixture of qualitative and quantitative information plus the uncertainties of various kinds that characterize it, is right for the expert approach. The first applications to be developed concerned above all, as it is natural, the hybrid methodologies (Casciati and Faravelli, 1989; Bernardini *et al.*, 1988). Other applications were directed towards decisions about the usability of buildings after an earthquake (Gavarini *et al.*, 1989).

Studies began to be developed about the vulnerability of constructions differing from ordinary buildings (Braga *et al.*, 1987a; Alessi *et al.*, 1990) and of geographically distributed systems (Corsanego and Del Grosso, 1988); a widening of the number of objects analyzed was gradually added to the widening of the methodology field.

But the newest problem, ever though tied to very old objects, raised during the last part of the decade, is probably that of the vulnerability of historic monumental buildings. In 1984, the National Committee for the Seismic Protection of Monumental Buildings and Italian Cultural Heritage (CNPPCRS) was already instituted, which had inserted vulnerability among its specific interest themes. It was evident that the scarcity of knowledge about the seismic behaviour of monuments did not allow yet the development of efficient theories concerning their damageability. It was therefore necessary to increase this knowledge considerably and to do that it was necessary to have a sufficient quantity of data. Thus a survey form was born which was experimented with on a certain number of buildings in Central Italy (Ceradini, 1987); it took on some characteristic of those of the GNDT first level, but paid particular attention to the building's history, to its state of decay and to its pathologies. To this was added a more recent relief methodology devised by researchers working in GNDT (Doglioni *et al.*, 1989), the most fundamental aspect of which was that of schematizing the historic building as an assembly of «constitutive elements». The latest developments have involved a more general framing of the acquisition of data about historic buildings in terms of a process to be articulated on several levels and including the expert approaches (Gavarini, 1990). The basic problem, which still exists today, is that of passing to the next phase in which original methods for the assessment of damageability will be introduced.

3. A summary scheme of methodologies

It could be useful to synthesize a number of observations made in the preceding section by means of a summary scheme of methodologies for estimating the seismic vulnerability of the constructions examined in this work.

There are four elements considered to draw up the scheme, namely the conceptual line followed, the kind of measure used to define the seismic vulnerability, the sort of results that emerge, the prevalent source of knowledge.

Here it has already been pointed out that there are three main conceptual lines from which the methodologies developed in recent years can be said to arise (typological, mechanistic, hybrid)

and it is therefore clear that from this point of view, these methodologies divide themselves into the following classes:

TY: typological methods,
ME: mechanistic methods,
HY: hybrid methods.

It has also been seen that the measure by which vulnerability is defined is, in general, based on numeric variables but that there are cases in which, instead, one turns to descriptive terms. Thus also the following methodology classification is useful:

QN: quantitative methods,
QL: qualitative methods.

The type of results produced allows a further distinction. It has been shown in fact that there are methods which give directly the forecast of damage, others which arrive indirectly because they are articulated in two steps (the first step consists of the specification of indicators of the weakness of the construction, while the second gives the forecast in terms of those indicators), while others give no forecast and specify the output in terms of a conventionally defined vulnerability.

A third classification is therefore possible:

DI: direct methods,
IN: indirect methods,
CO: conventional methods.

Finally, this treatise shows that until now the main source of knowledge has been the statistical processing of observations of previous earthquakes, or the analytical calculation of the seismic response, or the subjective judgement of experts.

The fourth classification comes out immediately:

ST: statistical methods,
AN: analytical methods,
SU: subjective methods.

The scheme is shown in table I in which, for compactness, the methods considered are indicated by number 01 (Alessi *et al.*, 1990), 02 (Beconcini *et al.*, 1990), 03 (Benedetti and Petrini, 1984), 04 (Benedetti *et al.*, 1984), 05 (Bernardini and Modena, 1986), 06 (Braga *et al.*, 1982), 07 (Braga *et al.*, 1987), 08 (Gavarini and Angeletti, 1984), 09 (Gavarini *et al.*, 1988), 10 (Giuffré *et al.*, 1988), 11 (Nuti *et al.*, 1987), 12 (Zaupa *et al.*, 1982). It gives a synthetic vision of the methodological orientations which have most characterized the research carried out in this field in Italy.

4. Conclusions

At the beginning of the Nineties one can claim that research into seismic vulnerability of constructions has seen quite important developments after the Irpinia earthquake.

The necessity for further studies into many subjects is still very great. One of them has particular importance in the Italian situation and is the above-mentioned vulnerability of monuments and historic buildings. Others, instead, are in common with other countries; we emphasize in particular the vulnerability of special constructions, that of the territorial systems, the relations between seismic damage and socio-economic consequences, the strategies for mitigating vulnerability, the extensive application of expert systems.

So it is essential, in Italy, that the assessments

Table I. A scheme of methodologies.

Method	01	02	03	04	05	06	07	08	09	10	11	12
Line	ME	ME	HY	HY	HY	TY	ME	HY	ME	HY	ME	HY
Measure	QN	QN	QN	QN	QN	QN	QN	QN	QN	QL	QN	QN
Results	DI	DI	IN	CO	DI	DI	DI	IN	DI	CO	DI	IN
Source	AN	AN	ST	SU	AN	ST	AN	ST	AN	SU	AN	ST

of seismic vulnerability become more part of the risk assessments; it is in fact clear that the knowledge of risk is the real goal to pursue in order to offer a rational basis for political decisions about the use of territory. This certainly calls for a closer interdisciplinary dialogue between the different specialistic research sectors. But it is also necessary for the theoretical risk studies to find verification in a substantial number of test cases in various Italian regions and this is only possible with an important contribution from Public Authorities, more than they have given up to now.

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