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Considerations on the seismic risk

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Abstract
The definitions of risk and hazard, and their meanings in engineering seismology, are given. The state-of-the-art of risk assessment and mitigation is discussed through a general panorama of the performed studies. Various ingredients can be accounted when considering the seismic risk: they go from statistical analysis of the regional seismicity to earthquake prediction and to people preparadness to a big future event. At present, studies connected to all of them should be stimulated, although the minimum goal remains the definition of a valid seismic code.

1. Risk and hazard

In the Webster's (1977) dictionary hazard is defined as «a source of danger» and risk as the «possibility of loss or injury» and the «degree of probability of such loss». Hazard, therefore, simply exists as a source, while risk includes the likelihood of conversion of that source into actual delivery of loss, injury, or some form of damage. The concept can, therefore, be expressed simbolically as (Kaplan and Garrik, 1981)

$$risk = uncertainty + damage \qquad (1)$$

$$risk = \frac{hazard}{safeguards} \qquad (2)$$

where eq. (2) shows that risk can be reduced by increasing the safeguards, if hazard remains constant. In other words, the risk associated to the occurrence of an event is determined by two factors: the probability of occurrence of such event, and the entity of its consequencies (Boschi, 1991). For the scientific community, irrespectively of the common use, hazard is synonymous of rare event not directly involving any special connotation of danger. It derives semantically from the arabic «azzahr», the dice, because dice players in Florence during the 13th century used to shout «zara» when the lowest probability result occurred (Siccardi, 1991).

Coming to engineering seismology, seismic hazard, or shakeability, represents the probability that a fixed value of shaking (macroseismic intensity, peak ground acceleration, etc.) could be exceeded in a certain time interval because of an earthquake, while risk describes quantitatively the probable damage that a site will experience (Slejko, 1988). A formal definition of seismic risk is not available; seismic risk takes into account the influence of three parameters: the seismic hazard, the vulnerability, and the value (or urban exposition), and even a simple rough quantification of risk is not possible by means of one physical quantity only (Fournier d'Albe, 1985). Precise definitions refer to the seismic hazard H, as said before, to the vulnerability V (measure of the attitude of a general object to suffer damage because of an earthquake; for more information on the building vulnerability see Petrini, 1991), and the value A (economic measure of the object or of its use). A notable difference between seismic hazard and risk does exist and, consequently, the use of the information is different: a seismic-hazard map can be the basis for the project of a seismically resistant building (although during the realization of the project choices of acceptable risk, on the basis of cost/benefit analysis, are made), and a seismic-risk map could indicate the zones where priority of reinforcement to old buildings is needed.

The seismic risk has been expressed analytically as the combination of three parameters (Ambraseys, 1983):

$$R = H \times V \times E \qquad (3)$$

where V qualifies the preservation status of the buildings as well as the situation of the social structures, lifelines, etc., which can go out of service because of the earthquake, and E is an economic measure of all the structures (human lives, buildings, factories, artistic works, etc.) hit. More precisely, H can be represented by HR + HL, where HR is the regional seismic hazard and HL is the local one. A parametric relation (the model) does not exist but different relations were applied under different conditions: for example the damage expected for different kinds of buildings was computed.

2. Examples of studies on the seismic-risk assessment

Usually, risk analyses are based on probabilistic studies or approaches by scenarios depending on the goal of the analyses themselves: probabilistic approaches are suitable to identify priorities of prevention intervention, while approaches by scenarios are suitable to civil protection planning (Petrini, 1991).

Some methodological examples for the quantitative assessment of the seismic risk have been performed in the last years. The seismological approach to the seismic-risk assessment leads to an evaluation of the global effects, while the engineering approach leads to a valutation of the most probable damage levels to some building classes. Generally both kinds of studies do not consider all the components of risk (HR, HL, V, E), because of the complexity of the problem but focus the attention only on a few (see table I), analyzing the consequent influence on the risk assessment. Ambraseys and Jackson (1981) have found strict correlation between total damage, normalized per demographic-density unity, and magnitude of the earthquakes which occurred during the last century in Greece and Turkey, and this correlation is even better considering different building types, although information on population and building types is not satisfactory. In this case HR, V, and E are taken into account and, therefore, the study gives a general idea of risk (see table I). The concepts of damage state (level) and damage probability matrix were introduced by Whitman and Cornell (1976) and can be considered the basis for the engineering approach. The vulnerability of the different building types is given by the distribution function of the damage probability which is associated to the damage state (which is given, for example, by the ratio between the cost for repairing the damage of a building and the cost for rebuilding it). As application of these concepts a social decision analysis of the earthquake safety problem has been performed by considering the unreinforced masonry buildings that were built in Los Angeles before 1933, that is prior to the code requirements designed to withstand earthquakes (Sarin, 1983). By considering four risk classes for the buildings on the basis of their importance or their occupant load, by postulating four scenarios of an earthquake in the Los Angeles Basin and their probabilities, by taking into account the consequencies on four building types to which the existing buildings can be upgraded by restoration, it resulted that the upgrading to the best-quality standards for essential buildings (schools, hospitals, fire stations, etc.) and to medium-quality standards for residential buildings represents the best cost/benefit balance. The occupants of the remaining buildings should be aware of the hazard. In this case, V and E are taken into account, while H is not probabilistically computed but postulated by scenarios (see table I). A similar result was found in Italy, where it was pointed out that differences in seismic hazard determine large differences of the expected damage only in the high-vulnerability buildings (Petrini, 1991). Also in Italy the seismic-risk assessment from the engineering point of view has been performed, as well as studies of variation of the risk after reinforcement interventions to existing buildings. A risk assessment based on the damage probability matrix (Whitman and Cornell, 1976) definition has been performed for the buildings of the historical centre of Gubbio in central Italy (Benzoni and Parisi, 1986) by using the information of the damage caused by a 5.5 magnitude earthquake which occurred in Spring 1984. The damage annual probability distribution for five damage classes and its variation because of three different reinforcement interventions are the results of the study. It is worth noting that the economic amount of the preserved damage within (51÷82) years will overcome the cost of the reinforcement intervention according to the different strategies taken, and, in any case, the softest reinforcement intervention reduces drastically the annual probability of severe damage, when even human lives are lost. This study was continued during the following years with more analysis on the damage and considering the Friuli region in north-eastern Italy too (Benedetti *et al.*, 1988). In the case of the two previous studies only V is adequately considered as risk descriptor (see table I).

Some quantitative risk assessments have been performed recently for the Friuli - Venezia Giulia region by expliciting eq. (3). Only some factors of risk have been considered because it is hard to quantify some parameters, as the vulnerability of the social and productive structures; therefore, the modelled and assessed risk is only a specific risk. A first example, more devoted to the methodology than to the actual calculation, refers to the Pordenone province in Friuli (Slejko *et al.*, 1988). In this study only statistical data published by the Regional Administration (demographic censa and requests for finantial support for restoration or rebuilding of buildings hit by the 1976 Gemona earthquake) have been considered and the risk model has been defined by expliciting eq. (3) with R taking the meaning of number of requests for financial support. The present risk for the Pordenone province has been subsequently calculated by considering the maximum expected shaking not exceeded at 63% probability in 200 years and the present values of V and A, defined according to the proposed model. A more rigorous application to the Friuli-Venezia Giulia region has been performed by

Table I. Elements of risk considered in some recent studies and during the symposium.

	Study	*HR*	*HL*	*V*	*E*	*R*
G	Ambraseys and Jackson, 1981	X		X	X	X
E	Sarin, 1983	O	O	X	X	X
N	Benedetti *et al.*, 1988			X		O
E	Benzoni and Parisi, 1986			X		O
R	Slejko *et al.*, 1988	X		X	O	X
A	Stucchi, 1988	X	X	X	X	X
L	Yang *et al.*, 1989	X		X		X
	Bortugno and Eisner, 1990	X	X	X	X	X
S	Corsanego, 1990	X	X	X	X	X
Y	Corsanego and Gavarini, 1990			X		
M	Grandori, 1990	X				
P	Hays and Hamilton, 1990	X	X	X	X	X
O	Kossobokov, 1990	X				X
S	Luongo and Marturano, 1980	X				
I	Mayer-Rosa *et al.*, 1990	X				
U	Siro and Del Grosso, 1990		X			
M	Stucchi, 1990	X				
	Thier, 1990			O	X	X

X = deeply, 0 = superficially.

means of the definition of the damage probability matrix for the rooms in the study region (Yang *et al.*, 1986, 1989). Rooms instead of houses were used because of their greater size homogeneity. The data for the definition of the damage probability matrix were taken from the damage reports after the 1976 Gemona earthquake. The so-defined model has been applied as to forecast the maximum expected damage at 37% probability in 100 years for the whole Friuli-Venezia Giulia region. Also in this case, as in the previous one, the vulnerability of the buildings has been defined according to their age and their behaviour during the 1976 earthquake, without, therefore, an actual analysis of their structural characteristics. In both cases, then, the results indicate only a possible way for assessing quantitatively the seismic risk and *HR*, *V*, and *R* are considered with only a slight consideration of *E* (see table I). The most interesting study on this subject remains the evaluation of the seismic risk of the town of Ancona (Stucchi, 1988). Its very peculiar characteristic is the goal of the study: it is directly devoted to support the drawing up and updating of the Town Plan, taking into account the seismological information and some geotechnical tests for a kind of microzoning, and the vulnerability and the exposition of the buildings for evaluating the expected damage. At the end suggestions to reduce the seismic risk to buildings and lifelines are given (see table I).

Such kind of studies are performed also by the insurance companies, that must forecast the possible economic impact of future earthquakes. Socio-economic analyses of the expected losses during the near future have pointed out that the highest risk is concentrated in the fastest growing cities, especially in the developing countries (Degg, 1991).

3. Ingredients of the seismic-risk assessment and mitigation

All the subjects which influence the total risk should be considered when planning a general project on the seismic risk. Each topic mentioned in table I contains various specific themes which contribute to its quantification. As an example, the subjects considered during the third session «Risk Assessment» of the symposium «Irpinia Dieci Anni Dopo» are described in the following, pointing out to which ingredient of the seismic risk they refer and evaluating, therefore, whether the session *in toto* can be considered a wide angle study of risk or some ingredients are still missing. The theme of the symposium was well established: it concerned the increase of knowledge on seismicity and seismic risk during the last decade. Although the main subjects of risk assessment and mitigation were considered, not for all of them an adequate example was found in Italy as well as around the world: actual actions for risk mitigation are hardly found, especially in Italy, with the exception of programs devoted to education and preparedness.

When considering the seismic-hazard assessment, the information expressed by geology and geophysics partecipates in the definition of the regional seismotectonic model, which is the basis for the subsequent hazard assessment. A seismotectonic model for Southern Italy is not worldwide accepted; this is due to the fact that the surface compressive tectonics cannot be easily connected to tensile mechanisms as those found for many strong Apenninic earthquakes (*e.g.*, the quake of November 23, 1980). A combined model with two motors (the expansion of the Tyrrhenian Sea and the Europe-Africa compression) can be proposed (Luongo and Marturano, 1990, see table I) and it seems to be consistent with the geological and geophysical evidences. The importance of the seismological data is of course predominant in the definition of the seismotectonic model and in the hazard assessment. The seismological data can be divided into two classes: the historical data and the instrumental data. The last class covers a very short period of time (less than one century), while the historical information covers at least one millenium in the European countries, and especially in Italy. A large spectrum of information can be derived when the seismological information is treated considering the macroseismic intensity. The recovery of the original data and their scientific analysis can increase greatly the knowledge of the historical seismicity, when based on an accurate strategy of research (Stucchi, 1990, see table I). In any case, the seismic hazard is based on a probabilistic elaboration of the seismological data set, or of a part of it. This elaboration is based upon some assumptions about the seismic process (*e.g.*, considering the earthquake occurrence as a Poisson process with exponential magnitude distribution of the events) which can be hardly tested. Then an idea about the errors can be introduced because of the initial assumptions that can be given by considering the random catalogues extracted from a synthetic catalogue constructed on the basis of a possible generating law (Grandori, 1990, see table I). But also accepting general assumptions for the earthquake process and considering similar seismotectonic information, the results of the statistical treatments for the hazard assessment, in terms of maximum expected shaking, can differ significantly. This fact was pointed out in the frame of an experiment of hazard assessment conducted by a working group composed by different teams (Mayer-Rosa *et al.*, 1990, see table I). Althought it is not the first example of seismic-hazard assessment for Southern Italy, it can be considered the most complete one.

The main tool for seismic-risk mitigation is given by the seismic code (see the Appendix), the application of which should guarantee a limited damage because of earthquakes. Another aspect of the seismic-risk mitigation refers to the prediction. Although this topic is still under debate and evident premonitory phenomena have been rarely identified, the statistical treatment of the seismological data set evidences sometimes at least the partial self-similarity of the earthquakes sequences in different seismotectonic environments and magnitude ranges (Kossobokov, 1990, see table I). Another aspect related to «before the earthquake» is given by the people education to earthquake occurrence. California is probably the brightest example of people preparedness (Thier, 1990, see table I), supported also by the information media. It is worth noting that the major efforts to such a project are supported by universities and public institutions. In this frame peculiar emphasis is given to studies related to the scenario for the next big earthquake in northern California (Bortugno and Eisner, 1990, see table I), where in addition to the direct effects (deaths and injuries, building collapses) also the secondary effects are taken into account (transportation and utility lifelines, etc.) for evaluating the persisting operativity of the essential public structures in the hit area. In any case, a 7-magnitude or larger earthquake in the San Francisco Bay area is rather probable (67% probability) within the next 30 years, and the expected damage in the urban area is expected to exceed 100 billion U.S. dollars at today's values (Hays and Hamilton, 1990, see table I). The U.S.A. and many other countries partecipate in a cooperative worldwide program called International Decade for Natural Disaster Reduction for finding opportune corrections and mitigating the effects. Soon after the 6.5-magnitude Irpinia earthquake of November 23, 1980, joint teams of geologists, seismologists and engineers surveyed the territory producing a kind of microzoning study of almost all the damaged villages for the future reconstruction. The produced study can be considered a mean point between microzoning and risk analysis. After that, further studies of actual immediate application were performed, among which that of Ancona for urban planning, that in Garfagnana and Lunigiana (Toscana) considering also the socio-economic impact of the possible quake, and that for forecasting the behaviour of the essential buildings in Toscana and Emilia-Romagna regions must be cited (Corsanego, 1990, see table I).

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Appendix: the Italian seismic code

As Italy is a high seismic country, the different governments which dominated parts of the territory faced the problem to preserve people and things from the earthquakes. The first legislative measures were taken by the Borbonic government after the 1783 earthquakes in Calabria, which caused more than 30 000 deads. In the following years, the choice of the sites for the rebuilding, as well as the construction standards, were considered by the law and by the regulations issued from the Pope state after the 1859 earthquake in Norcia. After the unity of Italy, all kinds of regulations decayed and the Italian state was unprepared to menage the situation after the 1883 earthquake which ruined all villages of Ischia island. The quake which destroyed Reggio Calabria and Messina on December 28, 1908 causing 80 000 deads was probably the strongest event in the Italian peninsula during the last ten centuries. Soon after the national seismic classification was promulgated: it consisted in the list of the municipalities of Sicily and Calabria, where technical rules for building, defined by the Royal Decree, were applied. The seismic classification was updated after every destructive earthquake simply adding municipalities to the official list: it was therefore based only on the fact that a municipality had experienced damage because of earthquakes after 1908, without any scientific consideration on the Italian seismicity and had principally the meaning of public aiding (for more details see Petrini, 1991). In 1974 a new seismic code was promulgated (law 64/1974) and it presents a kind of inner dynamics because it only states the criteria for constructing in a seismic area and the classification, intended as list of regulamented municipalities, is established by decree, and, therefore, it can be easily updated, after every damaging earthquake following the old phylosophy or, better, when the increased knowledge of the Italian seismicity requests a revision of the classification. Although the classified municipalities were inserted into two seismic categories according to the suffered damage, this distinction was rather fictious and it is not yet solved.

After the 1976 Gemona earthquake, the regional Public Administration asked to two public institutions (Osservatorio Geofisico Sperimentale of Trieste and Politecnico of Milano) the scientific support for planning the reconstruction of the destroyed villages. This can be considered the first urban intervention based on seismic-hazard studies (Faccioli, 1979; Giorgetti *et al.*, 1980). Only on the basis of probabilistic studies performed for Friuli an actual separation of the two seismic categories was possible.

Many different studies devoted to the knowledge of the Italian seismicity started after the 1976 Gemona earthquake, those studies were developed by the cooperation among geologists, geophysicists, and engineers in the frame of the Progetto Finalizzato Geodinamica of the Consiglio Nazionale delle Ricerche. One of the products were the maps of shakeability of Italy (Gruppo di Lavoro Scuotibilità, 1979; Petrini *et al.*, 1981) on the basis of which the CNR's proposal of seismic classification was based (see Petrini, 1980; Servizio Sismico del Consiglio Superiore dei Lavori Pubblici, 1986; Petrini *et al.*, 1987). That proposal was accepted by the Italian government and translated into a series of decrees by the Ministry of Public Works between 1980 and 1984. On the basis of probabilistic studies the resulted hazardous municipalities were inserted into the second category, leaving the already classified municipalities in their old position and defining a third category for some municipalities of Campania, where even low shakings could produce severe damage. A limit of this classification consists in considering only new buildings without planning reinforcement interventions on the existing buildings. In any case, the concept of risk is present, although not explicitly, in the Italian seismic code, for instance with the presence of the third category.

Generally speaking, we can say that the present Italian seismic code (classification and technical rules) considers all the three ingredients of the seismic risk, in fact in addition to the map of the three seismic categories some technical rules were fixed by law. These technical rules define the response spectrum for new buildings (the amplitude of the spectrum differs according to the seismic category only), evaluating therefore their vulnerability, and introduce a coefficient of seismic protection according to the importance of the building, evaluating therefore its value/exposition. In conclusion, the seismic classification should be the result of the national risk analysis, considering all the important ingredients. In addition, only evaluations of earthquake prediction could support a global knowledge of the seismic risk.

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