11 WCEE

Paper No. 298. (quote when citing this article)
Eleventh World Conference on Earthquake Engineering
ISBN: 0 08 042822 3

SEISMIC RISK ASSESSMENT IN THE HISTORICAL CENTRE OF ROME

M. DOLCE*, F. SABETTA**, R. COLOZZA**

* DiSGG, Università della Basilicata, 85100 Potenza
** Servizio Sismico Nazionale, Via Curtatone 3, 00198 Roma

ABSTRACT

A study on the seismic hazard, vulnerability and risk of damage of the residential buildings of the historical centre of Rome is presented. The vulnerability is assessed through a new expert-probabilistic-mechanical approach. The combination of hazard and vulnerability permits to get a probabilistic evaluation of the risk of heavy damage or collapse of the various buildings types, assuming the classical Poissonian hypothesis for the earthquake occurrence.

KEYWORDS

Hazard; Site Catalogue; Attenuation; Return Period; Uniform Hazard Spectra; Building Types; Seismic Vulnerability; Damage Mechanisms; Seismic Risk.

INTRODUCTION

The vulnerability assessment of the buildings of most Italian historical centres presents many peculiarities deriving from their long and complicated history. In particular the buildings of the historical centre of Rome have been subjected to several transformations, along many centuries of active life, which were often the result of single initiatives and modified hazardously the structural system. The residential settlements of the centre of Rome are then characterized by a high seismic vulnerability for most of the building types. On the other hand the territory of Rome has such a low seismic hazard, i.e. low probability of arrival of dangerous earthquakes, that a high resolution capability of the vulnerability analysis method is needed to make a reliable damage prediction.

For the above stated reasons the standard procedures for vulnerability analyses, which are based on the statistical treatment of the damage data from past earthquakes (Braga *et al.*, 1982), on empirical methods and expert judgement (Benedetti *et al.*, 1984), or on analytical-numerical procedures (Dolce *et al.*, 1994), appears inadequate for the problem at hand. An *ad hoc* vulnerability assessment method has been used, with a high resolution capability. It needs a preliminary historical analysis of the old buildings of Rome (Marconi, 1991; Sanfilippo, 1993) to define their structural characteristics and arrives to the Damage Probability Matrices of the various structural types through a purposely set up "expert-mechanical-probabilistic" approach.

HAZARD ASSESSMENT

The probabilistic methods for the assessment of the seismic hazard, which quantify the uncertainties in a typical random process like the earthquake generation, are widely used in different parts of the world (Algermissen and Perkins, 1976; Slejko *et al.*, 1993). Following these approaches the hazard is defined as the exceeding probability of a fixed value of ground shaking (e.g. macroseismic intensity, peak acceleration, spectral values, etc.) during a given period of time. For the historical centre of Rome two different probabilistic methods have been followed. The first (herein indicated as the Cornell method) was laid down by Cornell (1968) and, assuming that seismicity is a Poisson process whose event magnitude is exponentially distributed, requires a seismogenetic zonation, a seismic catalogue, and an attenuation law. The second is based on the use of a site catalogue reporting for each event the effects felt in Rome.

Methods

The Cornell method has been utilized by using the Seisrisk-III computer code (Bender and Perkins, 1987). An uncertainty of 15 km associated to the boundaries of the seismogenetic zones (SZ) proposed by "Gruppo Nazionale per la Difesa dai Terremoti" (Scandone *et al.*, 1991) has been assumed. In particular the SZ from n° 28 to n° 41, have been considered to affect the site of Rome (Fig. 1).

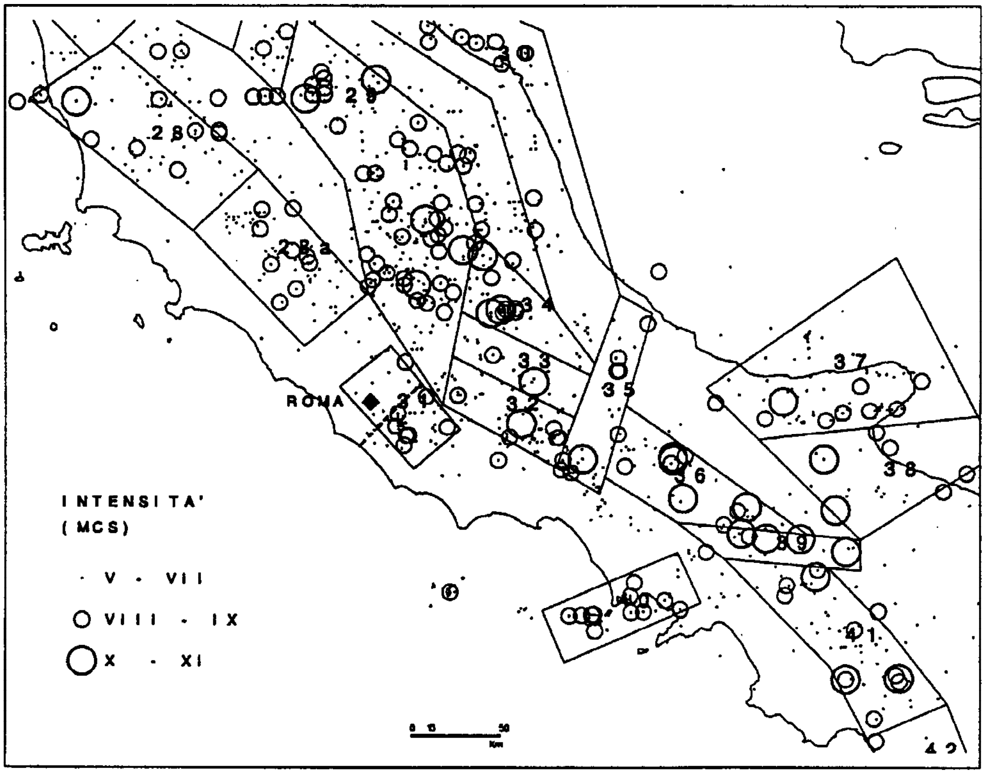

Fig. 1 Seismogenetic zones and epicenters used for the hazard assessment of Rome.

The zone n° 31 was modified, as shown by the dashed line in Fig. 1, in order to exclude Rome and preserve the contribution of the Alban Hills seismicity. The seismic catalogue compiled by "Progetto Finalizzato Geodinamica" (Postpischl, 1985) and including 37,000 events since year 1000 to 1980, was filtered with a methodology (Veneziano and Van Dyck, 1986) allowing to estimate for each earthquake the dimension of the space-time window to be used in order to remove the dependent events. The completeness intervals adopted are: since year 1250 for $I \geq \mathrm{IX}$; since 1680 for $I > \mathrm{VII}$; since 1780 for $I > \mathrm{VI}$; since 1850 for $I > \mathrm{IV}$. When the seismic events in the catalogue were characterized only by an intensity value, the intensity-magnitude conversion proposed by Karnik (1969) was adopted.

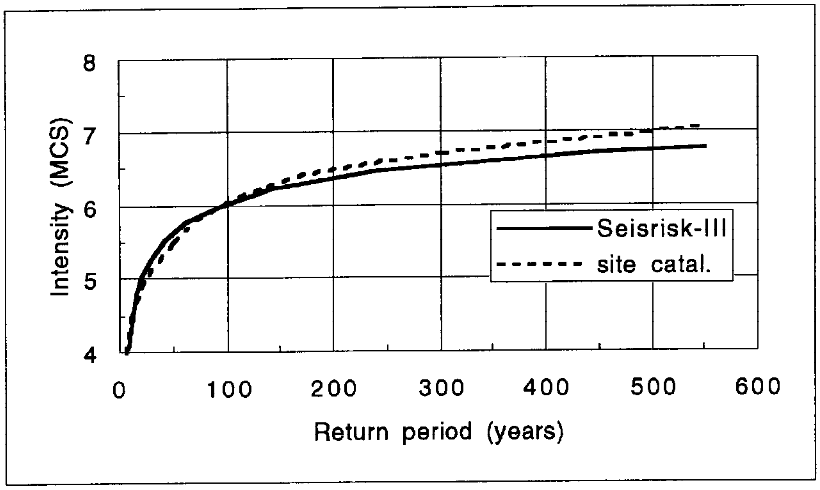

Fig. 2 Comparison of the results obtained with the site catalogue and the Seisrisk-III code

The hazard analyses were performed in terms of macroseismic intensity (Mercalli Cancani Sieberg, MCS scale), peak ground acceleration (PGA), peak velocity (PGV), and response spectral accelerations (SA) corresponding to 14 periods. The attenuation laws utilized were proposed by Grandori (1991) for intensities and by Sabetta and Pugliese (1987 and 1989) for peak values and spectral values.

The historical research on the seismicity of Rome (Molin et al., 1995) has yielded to a site catalogue including 656 events felt in Rome from 461 B.C. to 1989. The availability of a site catalogue is particularly useful because it avoids the most critical steps in the hazard analysis (seismogenetic zonation, intensity distribution and attenuation relationship). With this approach the hazard is directly obtained from the evaluation of the appearing frequencies of the intensities at the site. In Fig. 2 the results obtained with the site catalogue are compared to those derived from the national catalogue and the Seisrisk-III code: within the lowest uncertainty of half intensity degree, the results are almost identical, confirming the opportunity of the choices made in the application of Seisrisk-III (zonation, catalogue filtering, attenuation) and allowing to employ it to obtain further results in terms of ground motions parameters. In particular, for a 50 years return period, the expected intensity in Rome is V-VI MCS, whereas for long return periods (higher than 400 years), the intensity saturates towards VII MCS.

Results

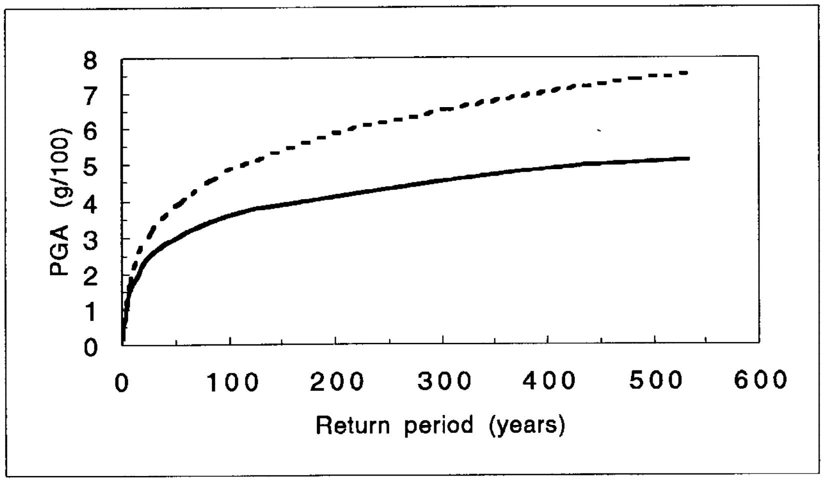

Fig. 3 Peak ground acceleration as a function of the return period

In Fig. 3 the trend of PGA vs. the return period is shown for the 50 and 84 percentile values derived from the standard deviation associated to the attenuation law (Sabetta and Pugliese, 1987). The median values correspond to about 0.03 g for a return period of 50 years and tend to saturate towards 0.05 g for long return periods.

Fig. 4 shows the exceeding probabilities of the spectral accelerations, corresponding to structural periods of 0.2 and 0.4 sec, for 50, 200, and 500 years observation intervals. The spectral values are derived from the attenuation law (Pugliese and Sabetta, 1989) for a stiff site and for a 5% critical damping. As an example the 0.4 sec. spectral accelerations having 10% probability of exceedance, correspond to 0.085 g in 50 years and about 0.14 g in 500 years.

To take into account the site amplification effects, two site classes, according to Pugliese and Sabetta (1989), have been considered: stiff sites (average shear wave velocity greater than 800 m/sec) and deep alluvium sites (shear wave velocity between 400 and 800 m/sec). Such classes correspond approximately to the main geological features of the historical centre of Rome (pleistocenic sediments and holocenic alluvium deposits of the Tiber valley). Figure 5 shows the uniform hazard spectra corresponding to a return period of 500 years, e.g. having a 37% probability of not being exceeded in 500 years, calculated for the above mentioned site classes. The alluvium sites show an amplification factor varying from 1.3 to 1.6 at periods between 0.4 and 3 seconds.

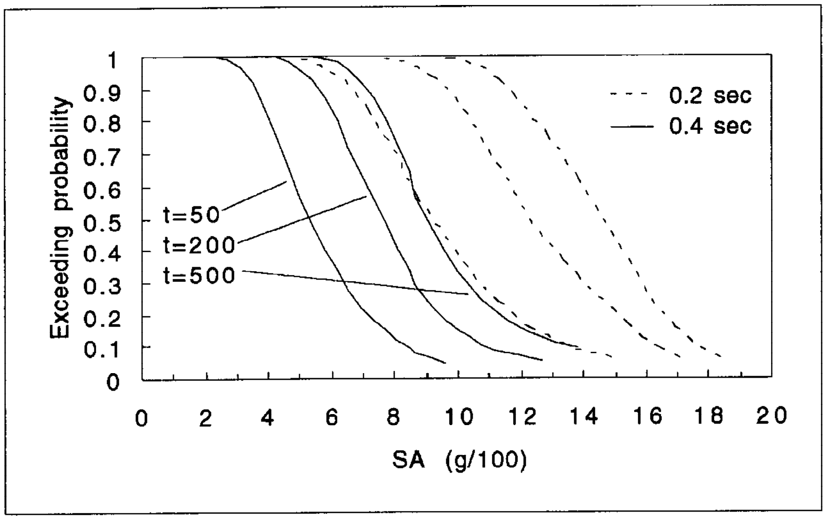

Fig. 4 Exceeding probability of spectral values (5% damping) at 0.2 and 0.4 sec corresponding to observation periods of 50, 200, and 500 years

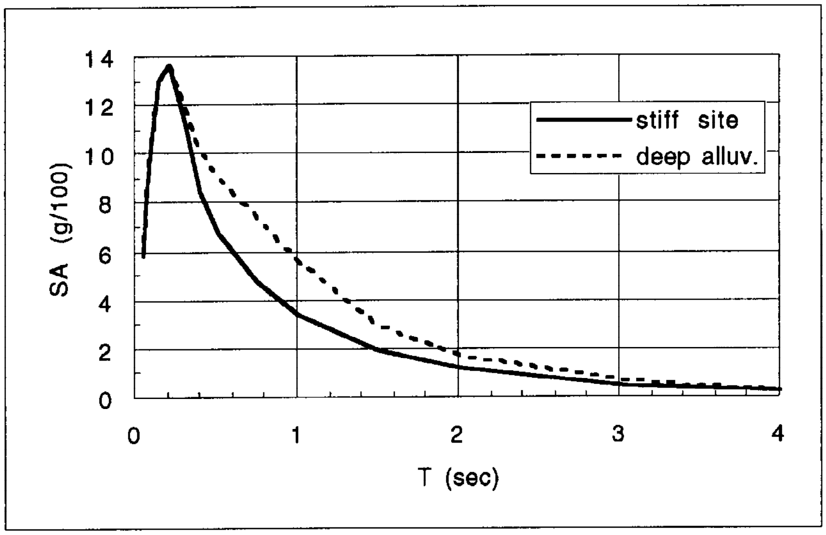

Fig. 5 Uniform hazard response spectra (5% damping) calculated for a return period of 500 years and for different local site conditions

STRUCTURAL CHARACTERIZATION OF THE BUILDING TYPES

The identification of the structural types is mainly derived from the architectural categorization and the inventory implemented by CLER (1986). In the present work, only the most common building types have been considered, so that the following main categories have been examined:

- Category A1: rows of single family residences of the XVII-XVIII century; buildings with a linear layout of the XVII-XVIII cent.; buildings with a linear layout of the XIX cent.;
- Category A2: mansions of XV, XVI, XVII century;
- Category B1: buildings with a linear layout transformed during the XIX century, obtained by assembling of serial building plots or substituting existing urban fabric;
- Category B3: XIX cent. blocks constituted by demolishing the pre-existing urban fabric or in new expansion areas.

This classification has been carefully re-examined and compared with the existing historical literature. Within these four categories, 11 structural types (see Tab. 2) have been identified. For each of them the structural characteristics that strongly affect the seismic response, such as the age of construction, the transformations, the dimensions, the type of foundation, the types of horizontal and vertical structures, the type and location of stairs, the functional scheme and the position of the openings in the façade, were identified.

VULNERABILITY ASSESSMENT

The fundamental steps of the procedure for each structural type are as follows:

a) Identifying the main damage and collapse mechanisms.
b) Evaluating, through simple static models, the seismic forces and the relevant peak ground accelerations which activate the above mechanisms, assuming a probabilistic distribution around those values, according to the variability of the geometry and of the materials. The seismic forces are then

transformed into spectral acceleration and peak ground acceleration. The latter transformation is needed to calibrate the results with respect to the observed damage distributions, as explained later.

c) Evaluating the probability of activating one or more damage mechanisms, for some given levels of seismic intensities, expressed in terms of peak ground acceleration;
d) Determining the conditional damage distributions for a given seismic intensity, under the hypothesis of binomial distribution (Braga *et al.*, 1982).

Several assumptions are made based on the historical-architectural analysis (geometry, wall thickness, etc.), the experience and the state of the art (material strengths, modelling). Their calibration is made by comparing the calculated and the observed damage distributions (Braga *et al.*, 1982; 1986).

Mechanisms of damage and collapse

The vulnerability evaluations are referred mainly to the mechanisms of collapse of the walls, by considering two groups of mechanisms: in-plane, and out-of-plane mechanisms. With reference to the typical situations of the old buildings of Rome, the failure modes considered are shown in Tab. 1.

Tab. 1 - Mechanisms and modes of damage and collapse.

a) in-plane mechanisms of damage and collapse		**a_1)** shear
		a_2) flexure of panels
		a_3) crushing of panels
b) out-of-plane mechanisms of damage and collapse	**b_1)** horizontal masonry lintels axially stressed	**b_{1a})** traction in connections of orthogonal walls
		b_{1b}) shear in connections of orthogonal walls
		b_{1c}) compression in the wall
	b_2) horizontal masonry lintels flexurally stressed	**b_{2a})** traction in connections of orthogonal walls
		b_{2b}) flexure in masonry lintel ends
		b_{2c}) flexure in the middle of masonry lintels
	b_3) overall cantilever behaviour due to ineffectiveness of orthogonal wall connections	

The values of the spectral ordinates activating the single mechanisms have been found through simplified evaluations (Bramerini *et al.*, 1995), and are shown in Tab. 2. They emphasize the low danger of some failure modes (b_{1a}, b_{1c}, b_{2a} b_{2c}), the high danger of some others (b_{2c} and b_3), the sensitivity with respect to the number of stories, and the danger of modes a_2, a_3, b_3 for tall (6-8 stories) buildings.

Evaluation of the damage probability distributions

It is assumed that the damage probability distributions can be modelled by binomial distributions B(n,k,p) (Braga *et al.*, 1986; Dolce *et al.*, 1994) where:

$$B(n,k,p) = \frac{n!}{k!(n-k)!}p^k(1-p)^{(n-k)} \qquad \text{with } 0 \le p \le 1; \ \text{k, n integer, positive}; \ k \le n$$

It is taken n=5, i.e. the number of damage levels considered in the MSK scale. The distribution is a function only of the parameter p. To calibrate p, the following procedure has been set up.

1) For each mechanism, the activating ground acceleration is evaluated by dividing the activating spectral acceleration by an amplification coefficient. This is taken equal to 2 for 1-2 story and 7-8 story buildings, and 2.5 for 3 to 6 story buildings, according to the approximate average amplification factors of the earthquake for which observed damage distributions are available (Braga *et al.*, 1982).
2) The probability of activating each mechanism for a reference value of the ground acceleration is evaluated by assuming a normal distribution with 0.4 coefficient of variation and by calculating the probability that the activating acceleration is less than the reference acceleration
3) The total probability of activating any mechanism, given the structural type, the number of stories and the type of seismic input, is evaluated with the assumption that the activation of the various

mechanisms are mutually exclusive or independent events. Within the same group, the following mechanisms are assumed to be independent: a_1, a_2, a_3 in the 1st group; b_{1a}, b_{1c} in the 2nd group; b_{2a}, b_{2b}, b_{2c} in the 3rd group. Mechanisms b_1, b_2, b_3 are considered mutually exclusive.

4) The parameter p is then evaluated by equating the probabilities calculated at step 3 to those corresponding at least to a damage level 2. The variables which affect p are then calibrated by comparing the p-values to those relevant to the '80 and '84 Italian earthquakes (Braga *et al.*, 1986) for similar building types.

Tab. 2 - Mean spectral accelerations (in g) for activating the damage and collapse mechanisms for 11 structural types

BUILDING TYPE	a1	a2	a3	b1a	b1c	b2a	b2b	b2c	b3
A1 - 1-2 stories	0.859	0.430	6.243	0.505	0.992	0.505	0.423	0.118	0.112
A1 - 3-4 stories	0.532	0.266	1.467	0.505	0.992	0.505	0.423	0.118	0.074
A11 - 1-2 stories	0.859	0.430	6.243	0.505	0.992	0.505	0.423	0.118	0.112
A11 - 3-4 stories	0.532	0.266	1.467	0.505	0.992	0.505	0.423	0.118	0.074
A11 - 5-6 stories	0.411	0.206	0.610	0.505	0.992	0.505	0.423	0.118	0.061
A12 - 1-2 stories	0.800	0.400	5.625	0.545	0.826	0.545	0.353	0.098	0.093
A12 - 3-4 stories	0.499	0.249	1.313	0.545	0.826	0.545	0.353	0.098	0.061
A12 - 5-6 stories	0.387	0.194	0.542	0.545	0.826	0.545	0.353	0.098	0.051
A12 - 7-8 stories	0.327	0.163	0.281	0.545	0.826	0.545	0.353	0.098	0.046
A13 - 1-2 stories	0.577	0.289	3.375	0.505	0.992	0.505	0.423	0.118	0.112
A13 - 3-4 stories	0.373	0.186	0.750	0.505	0.992	0.505	0.423	0.118	0.074
A13 - 5-6 stories	0.294	0.147	0.292	0.505	0.992	0.505	0.423	0.118	0.061
A13 - 7-8 stories	0.250	0.125	0.141	0.505	0.992	0.505	0.423	0.118	0.055
A14 - 1-2 stories	0.653	0.327	4.125	0.505	0.992	0.505	0.423	0.118	0.112
A14 - 1-2 stories	0.416	0.208	0.938	0.505	0.992	0.505	0.423	0.118	0.074
A14 - 5-6 stories	0.327	0.163	0.375	0.505	0.992	0.505	0.423	0.118	0.061
A22 - 1-2 stories	0.653	0.327	4.125	0.505	0.992	0.505	0.423	0.118	0.112
A22 - 3-4 stories	0.416	0.208	0.938	0.505	0.992	0.505	0.423	0.118	0.074
A22 - 5-6 stories	0.327	0.163	0.375	0.505	0.992	0.505	0.423	0.118	0.061
B11 - 1-2 stories	0.577	0.289	3.375	0.505	0.992	0.505	0.423	0.118	0.112
B11 - 3-4 stories	0.373	0.186	0.750	0.505	0.992	0.505	0.423	0.118	0.074
B11 - 5-6 stories	0.294	0.147	0.292	0.505	0.992	0.505	0.423	0.118	0.061
B11 - 7-8 stories	0.250	0.125	0.141	0.505	0.992	0.505	0.423	0.118	0.055
B12 - 1-2 stories	0.539	0.269	3.938	0.390	0.771	0.390	0.370	0.103	0.111
B12 - 3-4 stories	0.350	0.175	0.844	0.390	0.771	0.390	0.370	0.103	0.069
B12 - 5-6 stories	0.277	0.138	0.313	0.390	0.771	0.390	0.370	0.103	0.055
B12 - 7-8 stories	0.236	0.118	0.141	0.390	0.771	0.390	0.370	0.103	0.048
B13 - 1-2 stories	0.479	0.239	3.188	0.429	0.933	0.429	0.448	0.124	0.122
B13 - 3-4 stories	0.315	0.157	0.656	0.429	0.933	0.429	0.448	0.124	0.078
B13 - 5-6 stories	0.250	0.125	0.229	0.429	0.933	0.429	0.448	0.124	0.064
B13 - 7-8 stories	0.213	0.107	0.094	0.429	0.933	0.429	0.448	0.124	0.057
B31 - 3-4 stories	0.277	0.138	0.429	0.303	0.511	0.303	0.244	0.074	0.067
B31 - 5-6 stories	0.241	0.120	0.190	0.303	0.511	0.303	0.244	0.074	0.049
B31 - 7-8 stories	0.221	0.111	0.107	0.303	0.511	0.303	0.244	0.074	0.040
B32 - 3-4 stories	0.277	0.138	0.893	0.303	0.511	0.303	0.244	0.074	0.067
B32 - 5-6 stories	0.241	0.120	0.397	0.303	0.511	0.303	0.244	0.074	0.049
B32 - 7-8 stories	0.221	0.111	0.223	0.303	0.511	0.303	0.244	0.074	0.040

After calibration, the same procedure has been applied by considering the spectral instead of the ground acceleration. The parameter p is the mean damage value in a 0 to 1 scale. By substituting its value in the above shown binomial distribution, the probability of damage in a 0 to 5 scale can be evaluated.

RISK ASSESSMENT

To evaluate the risk of damage or collapse of the various structural types, the classical Poisson hypothesis is assumed, with arrival annual frequency λ. In the present study only the annual frequency of heavy damage and collapse has been evaluated (damage level 4 or 5), following the procedure outlined below:

1) evaluation of the annual frequency of occurrence $\Delta\lambda$ of the various spectral accelerations, for different site conditions and fundamental periods of the buildings, from the data presented in Figures 4 and 5;
2) evaluation of $p(S_a)$ in the binomial distribution of damage for a given spectral acceleration S_a;
3) evaluation of the conditional probability of heavy damage or collapse, for each spectral acceleration: $P[D>3 \mid S_a] = 5 \cdot p(S_a)^4 \cdot [(1-0.8 \cdot p(S_a)]$;
4) evaluation of the annual frequency λ_d of heavy damage or collapse as the sum of the products of the annual frequencies by the relevant probabilities of heavy damage or collapse for all accelerations;
5) evaluation of the total probability of heavy damage or collapse during a given period of observation t with the following formula: $P[D>3] = 1 - e^{-\lambda_d t}$

The annual frequencies of heavy damage or collapse are shown in Tab. 3 with reference to the site categories utilized (stiff and alluvium) and to the position of the buildings (internal and external stand for central and extreme position in linear layout buildings). The higher risk level of the low-medium rise buildings can be ascribed to the low amplification factor of the spectral ordinate for long vibration periods, resulting from the greater influence of low magnitude earthquakes in the hazard assessment (see Fig. 5).

Tab. 3 - Annual frequency of heavy damage or collapse for different site conditions and positions of the buildings

	STIFF			**ALLUVIUM**		
	internal	**block**	**external**	**internal**	**block**	**external**
A1 - 2 stories	1.72 E-04	2.70 E-04	4.06 E-04	1.72 E-04	2.70 E-04	4.06 E-04
A1 - 4 stories	4.06 E-05	5.64 E-05	7.69 E-05	7.48 E-05	1.08 E-04	1.52 E-04
A1 - 6 stories	3.37 E-05	4.15 E-05	5.08 E-05	9.07 E-05	1.17 E-04	1.48 E-04
A1 - 8 stories	1.73 E-05	1.94 E-05	2.18 E-05	8.48 E-05	1.00 E-04	1.18 E-04
A2 - 2 stories	1.34 E-04	2.15 E-04	3.31 E-04	1.34 E-04	2.15 E-04	3.31 E-04
A2 - 4 stories	4.06 E-05	5.16 E-05	6.47 E-05	7.53 E-05	9.75 E-05	1.25 E-04
A2 - 6 stories	3.13 E-05	3.52 E-05	3.95 E-05	8.40 E-05	9.72 E-05	1.12 E-04
B1 - 2 stories	1.86 E-04	2.78 E-04	4.07 E-04	1.86 E-04	2.78 E-04	4.07 E-04
B1 - 4 stories	5.10 E-05	6.58 E-05	8.38 E-05	9.58 E-05	1.27 E-04	1.67 E-04
B1 - 6 stories	3.92 E-05	4.73 E-05	5.67 E-05	1.10 E-04	1.37 E-04	1.70 E-04
B1 - 8 stories	1.75 E-05	1.98 E-05	2.24 E-05	1.02 E-04	1.18 E-04	1.36 E-04
B3 - 4 stories	9.12 E-05	1.35 E-04	1.95 E-04	1.78 E-04	2.76 E-04	4.12 E-04
B3 - 6 stories	5.17 E-05	7.18 E-05	9.78 E-05	1.55 E-04	2.26 E-04	3.21 E-04
B3 - 8 stories	1.45 E-05	2.07 E-05	2.62 E-05	8.79 E-05	1.32 E-04	1.75 E-04

CONCLUSION

The historical centre of Rome has represented an ambitious test for setting up mixed methods to evaluate the seismic risk of big cities, as they are often characterized by a complicated history of their urban development, a moderate hazard and a good knowledge of their seismicity. The proposed approach makes use of different sources of information such as: historical-architectural information, expert judgement, simplified structural models, statistical damage data from past earthquakes in other sites. The assemblage of these informations through a probabilistic procedure, allowed to evaluate the absolute vulnerability in terms of damage probability, to make different assessments for buildings that in other approaches would have been assigned the same vulnerability, and to express the seismic intensity in terms of spectral accelerations for risk assessment. The new methodology can be potentially applied to other historical settlements.

As expected, the seismic hazard of Rome resulted to be quite low, showing values that, even for long return periods, do not exceed VII MCS for intensity and 5% g for PGA. The combination of the low hazard with the high vulnerability of most of the old buildings, gives global risk values that are definitely not negligible. In terms of annual exceeding frequency of serious damage or collapse, the results range from 4.12×10^{-4} for a 4-stories building of the weakest structural typology on alluvium, to 1.73×10^{-5} for a 8-stories building of the strongest structural typology on stiff site.

REFERENCES

Algermissen, S.T., D. M. Perkins, W. Isherwood, D. Gordon, G. Reagor and C. Howard (1976). Seismic risk evaluation of the Balkan region, *Proc. of the Seminar on seismic zoning maps, Unesco*, Skopie, 172-240.

Bender, B. and D.M. Perkins (1987). Seisrisk III : A computer program for seismic hazard estimation., *U.S. Geological Survey Bulletin*, 1772, 48 pp.

Benedetti, D. et al., (1984). Indagine sulla vulnerabilità sismica degli edifici di Pozzuoli, *Proc. 2 Congresso Ingegneria Sismica in Italia*, Rapallo, 3, 63-84.

Braga, F., M. Dolce and D. Liberatore (1982). Southern Italy November 23, 1980 Earthquake: A Statistical Study on Damaged Buildings and an Ensuing Review of the M.S.K.-76 Scale, *Proc. 7th Europ. Conf. on Earthq. Eng.*, Athens, *pubblication CNR-PFG n.503*, Rome.

Braga, F., M. Dolce and D. Liberatore (1986). Assessment of the relationship between macroseismic intensity, type of building and damage, based on the recent Italy earthquake data, *Proc. 8th Europ. Conf. on Earthq. Eng.*, Lisbon, 1, 3.1, 39-46.

Bramerini, F., R. Colozza, S. Coppari, M. Dolce, M. Moscato, A. Paciello, M. Rebuffat and F. Sabetta (1995). Rischio sismico nel centro storico di Roma, *La geologia di Roma - Memorie descrittive della carta geologica d'Italia, Istituto Poligrafico e Zecca dello Stato, Roma*, Vol. L, VIII, 437-545.

C.L.E.R. (1986). La mappa delle categorie edilizie, "Una regola per il recupero", *Assessorato per gli Interventi sul Centro Storico di Roma, Ed. F.lli Palombi, Roma.*

Cornell, C.A. (1968). Engineering seismic risk analysis, *Bull. Seism. Soc. Am.*, 58, 1583-1606.

Dolce, M., A. Kappos, G .Zuccaro, and A.W.Coburn (1994). State of the Art Report of W.G. 3: Vulnerability and Risk analysis, *Proc. 10th Europ. Conf. on Earthq. Eng.*, Wien, 4, 3049-3077.

Grandori, G., A. Drei, F. Perotti and E. Tagliani (1991). Macroseismic intensity versus epicentral distance: the case of Central Italy, *Tectonophysiscs*, 193, 165-171.

Karnik, V. (1969).Seismicity of the european area, *Reidel Publ. Company, Dordrecht*, 364 pp.

Marconi, P. (1991). Uno strumento per una città migliore, *Atlante di Roma, Ed. Marsilio , Roma.*

Molin, D., S. Castenetto, E. Di Loreto, E. Guidoboni, L. Liperi, B. Narcisi, A. Paciello, F. Riguzzi, A. Rossi, A. Tertulliani and G. Traina (1995). Sismicità di Roma, *Memorie descrittive della carta geologica d'Italia, Istituto Poligrafico e Zecca dello Stato, Roma*, Vol. L, VI, 331-408.

Postpischl, D. (1985). Catalogo dei Terremoti Italiani dall'anno 1000 al 1980, *CNR P.F. Geodinamica, Graficoop Bologna*, 164 pp.

Pugliese, A. and F. Sabetta (1989). Stima di spettri di risposta da registrazioni di forti terremoti italiani., *Ingegneria Sismica*, 6, 3-14.

Sabetta, F. and A. Pugliese (1987). Attenuation of peak horizontal acceleration and velocity from italian strong-motion records., *Bull. Seism. Soc. Am.*, 77, 1491-1513.

Sanfilippo, M. (1993). Le tre città di Roma, *Ed. Laterza, Bari* .

Scandone, P., E. Patacca, C. Meletti, M. Bellatalla, N. Perilli and U. Santini (1991) Struttura geologica, evoluzione cinematica e schema sismotettonico della penisola italiana, *GNDT, Atti del Convegno 1990, Tip. Moderna Bologna*, 1, 119-133.

Slejko, D., L. Peruzza and A. Rebez (1993). Pericolosità sismica del territorio nazionale: prima fase, *GNDT Rapporto interno- OGS, Rel. 41/93-OGA12, OGS, Trieste*, 145 pp.

Veneziano, D. and M. Van Dyck (1986).Seismic hazard analysis for the Friuli Region. Part I: magnitude conversion and earthquake clustering, *Rapporto interno ENEA*, Roma, 163 pp.