ANNALI DI GEOFISICA, VOL. XXXVIII, N. 5-6, November-December 1995

Earthquakes in Rome during the past one hundred years

Andrea Tertulliani and Federica Riguzzi
Istituto Nazionale di Geofisica, Roma, Italy

Abstract
We have studied the seismic response of the city of Rome using the available macroseismic data of local earthquakes which occurred during the past one hundred years. These earthquakes were generated by three distinct seismogenic sources falling within the present extent of Rome. The comparison with the effect produced in Rome by a large Apennine earthquake (January 13, 1915) suggests that the damage patterns are similar and that they are mainly controlled by the local geology and morphology. The analysis shows that most of the damage was concentrated in buildings located on alluvial deposits of the Tiber River rather than in buildings underlain by different lithologies. In addition, the largest concentration of heavy damage occurred in buildings located on the alluvial deposits of the right-hand side of the Tiber River valley, and particularly where the buried interface between Holocene and Pliocene deposits is steepest. This close relationship between damage pattern on the one hand, and geology and geometry of the shallowest deposits on the other hand, supports the results of ground motion modeling studies of the same area and similar observations collected in different regions of the world during large earthquakes.

Key words *Rome – historical center – seismicity – damage pattern*

1. Introduction

The seismic hazard in the city of Rome is mainly associated with the activity of two distinct seismogenic areas: the Central Apennines, from Umbria to Irpinia, and the Alban Hills volcanic complex, located approximately 25 km southeast of Rome (fig. 1).

The seismic response of Rome to large earthquakes occurring in the Apennines such as those of 1349, 1703 and 1915, was extensively analyzed by Molin and Guidoboni (1989). The maximum intensity felt in Rome for those earthquakes was VII-VIII MCS. Furthermore, many investigators (Boschi *et al.*, 1989; Funiciello *et al.*, 1992; Iodice *et al.*, 1992, Rovelli *et al.*, 1994) have recently studied the seismic response of Rome through modeling of local amplifications of the seismic motion produced by the 1915 Avezzano earthquake and in general by large Apennine earthquakes. All these studies show that the amplifications of the ground motion occur along the Tiber River valley, where a bedrock of consolidated clays is overlain by Holocene deposits of variable thickness. This same area of Rome underwent the largest concentration of damage following the 1915 Avezzano earthquake (Ambrosini *et al.*, 1986).

The second source of earthquakes felt in the city of Rome is that of the Alban Hills, a volcanic complex located 15 to 35 km to the southeast of Rome which was investigated thoroughly by Amato *et al.* (1994). The seismicity of this area extends to the southern outskirts of Rome, and in the past it has produced earthquakes that were felt in the city with an intensity up to VI-VII MCS (Molin *et al.*, 1986).

The area of Rome also has a local source of seismic activity which however is scarcely known. This activity has been studied in the

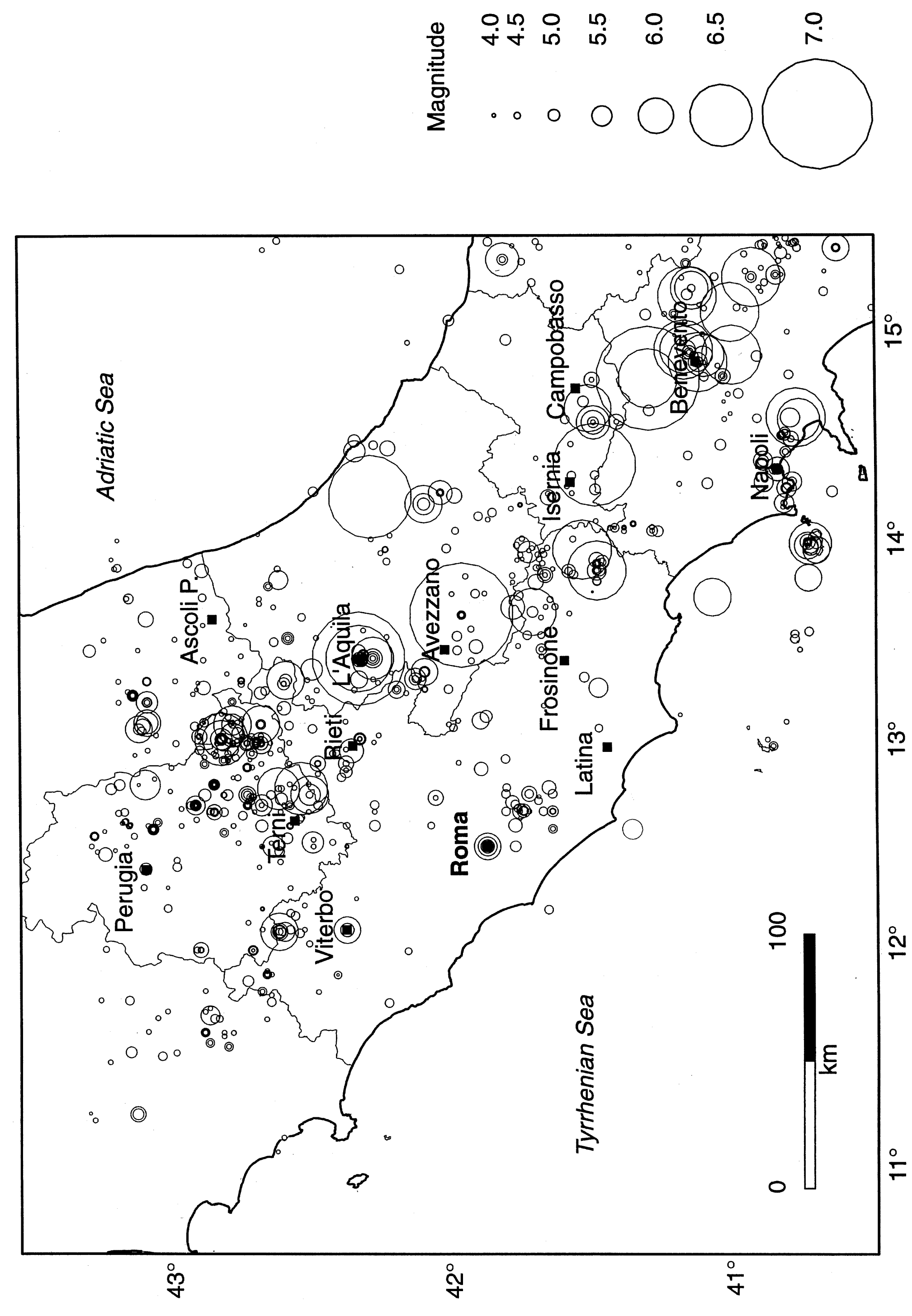

Fig. 1. Seismicity of Central Italy from the Italian Seismic Catalogue.

past (Tacchini, 1895; Martinelli, 1913; Agamennone, 1922) and recently re-analyzed by Riguzzi and Tertulliani (1993). What we refer to as the area of Rome is a region with a radius of about 15 km from the center of the city. Previous studies have shown that the earthquakes of this region reached intensities up to VII MCS with localized amplifications in the districts built on the sedimentary deposits.

2. Investigation

We characterized the local seismicity of Rome using macroseismic data and historical sources along with the epicentral location of recent events. The employed dataset is based on the historical re-examination of Riguzzi and Tertulliani (1993) and on other sources (De Panfilis, 1970), as well as on a careful screening of the ING Seismic Catalogue and Bulletins.

We identified three different areas that may be responsible for earthquakes of moderate size but large enough to cause panic and damage in the city, especially in the historical part of Rome (fig. 2). Table I shows the relationship between the three areas, the associated events and the center of the city (Campidoglio, $\phi = 41.89$, $\lambda = 12.48$).

The 1895 earthquake is indeed the largest to have shaken Rome and its countryside, causing damage in many buildings and churches and

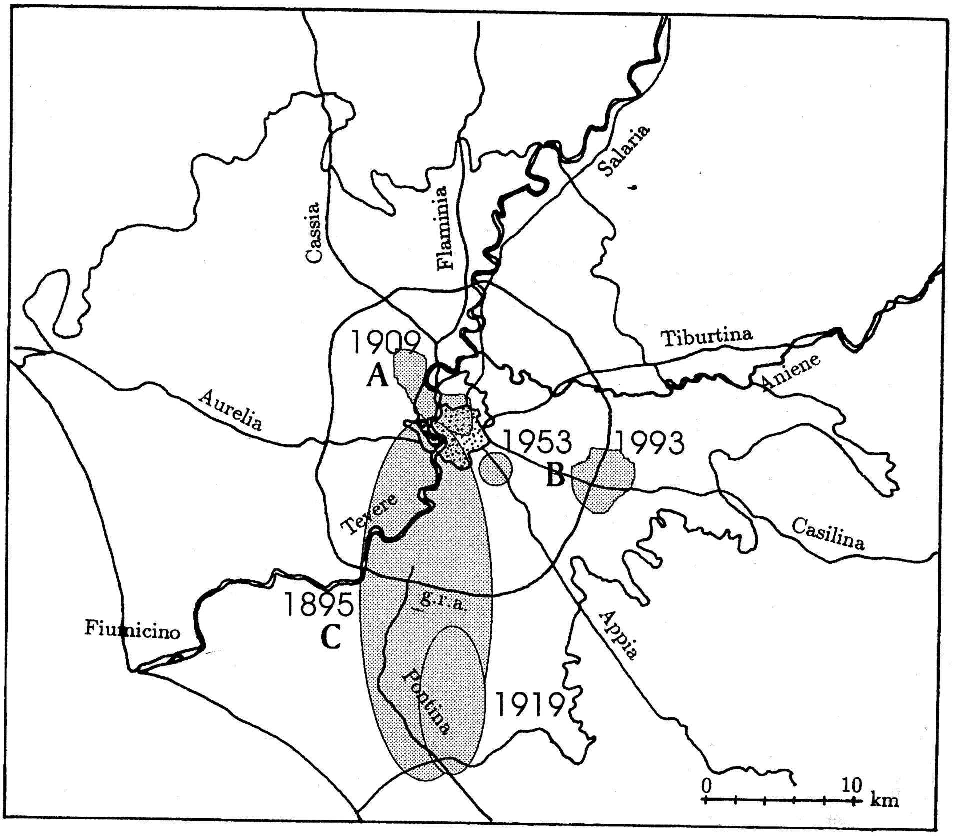

Fig. 2. Seismogenic areas in Rome. Maximum intensity areas are indicated for each event. A: 1909, $M_L = 3.6$, $I_0 = \text{VI}$; B: 1953 $I_0 = \text{IV}$ and 1993 $M_L = 2.7$, $I_0 = \text{IV}$; C: 1895 $I_0 = \text{VII}$ and 1919 $I_0 = \text{V-VI}$.

Table I. List of the local events which occurred in Rome during the last one hundred years with their epicentral areas (as in fig. 2). Magnitude is indicated when available, intensity is in MCS scale.

Area	Event	M_L	I_0
A	1909	3.6	VI
B	1953	–	IV
	1993	2.7	IV
C	1895	–	VII
	1919	–	V-VI

leaving traces that are still visible today (figs. 3 and 4).

Riguzzi and Tertulliani (1993) reevaluated the macroseismic intensity of those local events using the standard ING criteria for macroseismic analysis (Gasparini *et al.*, 1992) and produced new macroseismic fields for the 1895 and 1909 earthquakes.

According to Tertulliani and Riguzzi (1993), the area of maximum intensity (VII MCS) of the 1895 earthquake stretched toward the center of Rome, while other investigators (Tacchini, 1895; Molin *et al.*, 1986) contended that the epicentral area was located between Rome and Fiumicino, along the Tiber River. The existence of the seismic source to the south of Rome (fig. 2, zone C) that we hypothesized is confirmed by the occurrence of the 1919 earthquake that produced no damage. Agamennone (1922) studied this event and located its epicentral area as shown in detail in fig. 5. Instrumental bulletins also show widespread microseismicity in the same area.

The macroseismic field of the 1909 event it is much more complicated as it is characterized by two areas of maximum intensity: one overlaps the epicentral zone originally defined by Martinelli (1913), between Via Cassia and Via Trionfale, to the northwest of the historical center of Rome (fig. 2, zone A); while the

MDCCCXCVI
DOPO I GRAVI DANNI
CAGIONATI DAL TERREMOTO DEL 1 NOV. 1895
GLI AMMRI E GOVERNRI DEL MONTE CARAFA
MONS. L. SALVATI SEGRIO DELLA S. C. DEL CONCILIO
MONS. A. CIASCA SEGRIO DELLA S. C. DE PROP. FIDE
RAFFORZARONO CON SPERONE E CATENE
IL PALAZZO E LA CHIESA
ETTORE CAV. BONOLI ARCHI
CARLO CAV. CORTINI AGENTE

Fig. 3. Stone engraving commemorating the damage suffered by the Alberoni Palace, located to the south of Rome, following the 1895 earthquake (Riguzzi and Tertulliani, 1992).

Fig. 4. Reinforcement wall for the damaged edge of the Alberoni Palace.

other lies within the historic Aurelian Walls. The damage suffered by this part of Rome, along the Tiber River valley, was minor but rather widespread.

Three small events, two in April 1953, IV MCS and the last in January 1993, $M_L = 2.7$, intensity IV MCS, were generated within the third seismogenic area, located to the east of Rome (fig. 2, zone B).

To determine the response in terms of damage of the historical area of Rome to different kinds of earthquakes (local or external) we analyzed the distribution of damage in the part of the city enclosed by the Aurelian Walls. Similarly to the

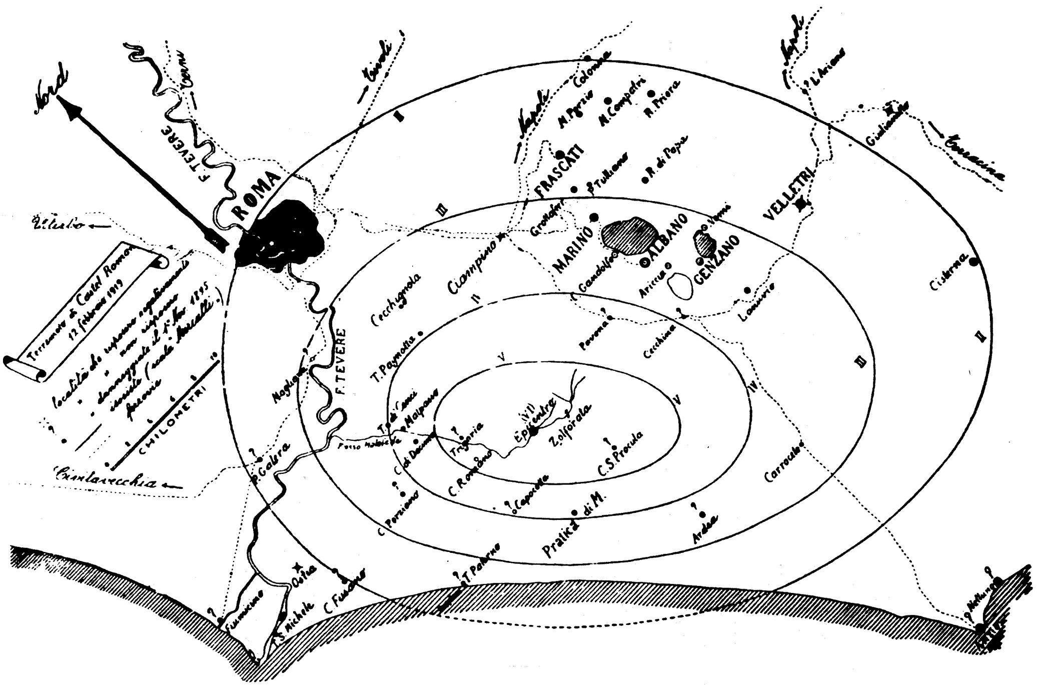

Fig. 5. Isoseismal map of the 1919 Castel Romano earthquake (from Agamennone, 1922).

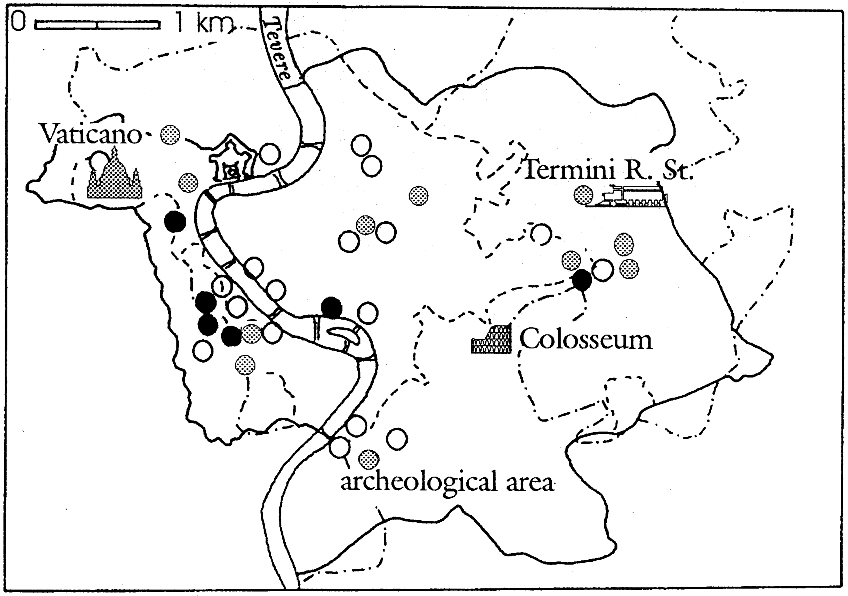

Fig. 6. Map of the historical center enclosed by the Aurelian Walls, showing the distribution of damage following the 1895 and 1909 earthquakes.

approach used by Ambrosini *et al.* (1986) for the 1915 Avezzano earthquake, we normalized the macroseismic observations collected for both the 1895 and 1909 events inside the Aurelian Walls so that their associated damage distribution could be compared with the damage suffered in 1915.

We therefore separated the kinds of damage into three categories:

Maximum damage:

- 1895: partial collapses, many tiles twisting and falling, large cracks in the walls;
- 1909: tiles falling and twisting, many cracks with plaster falling.

Medium damage:

- 1895: slight damage in many buildings, plaster falling, cracking and falling of monumental ornaments;
- 1909: many hairline cracks, a few monumental ornaments falling.

Minimum damage:

- 1895: slight damage in poorly constructed buildings, small pieces of mortar falling, thin cracks in plaster;
- 1909: some hairline cracks.

Figure 6 shows a map of the center of Rome with the damage associated with the 1895 and 1909 earthquakes. The most severe damage is concentrated in the Tiber River valley, and particularly along its right-hand bank, on buildings located at the Gianicolo foot. The regular urbanization of the historical center in that period (Istituto Geografico Militare, 1907-1908) enhanced the occurrence of this phenomenon.

Comparing this damage distribution with that associated with the 1915 Avezzano earthquake (80 km to the east of Rome) we note a coincidence of damage concentration along the alluvial valley (fig. 7).

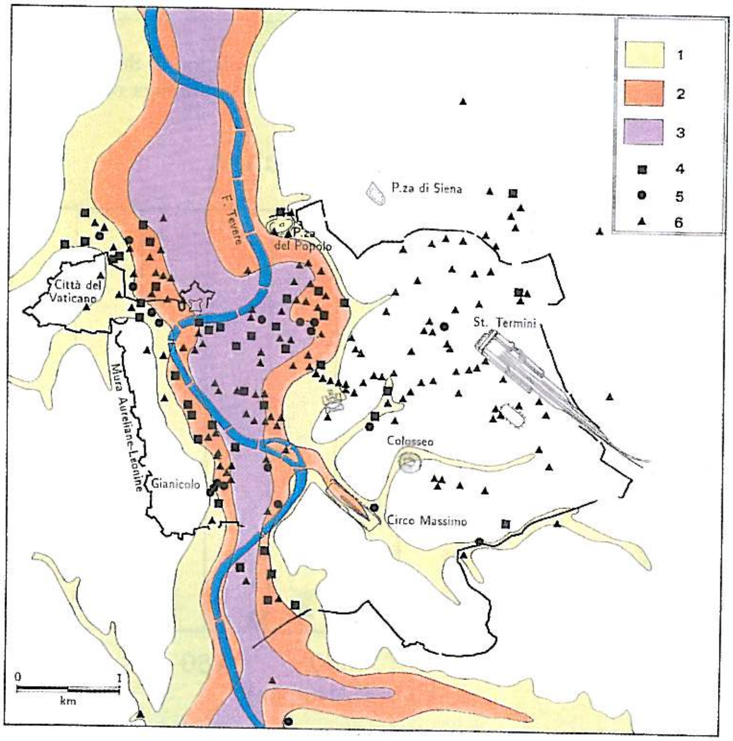

Fig. 7. Distribution of the damage caused by the 1915 Avezzano earthquake, plotted against thickness of the alluvial deposits (from Boschi *et al.*, 1993). 1: thickness 0-20 m; 2: 20-60 m; 3: over 60 m; 4: heavy damage; 5: medium damage; 6: slight damage.

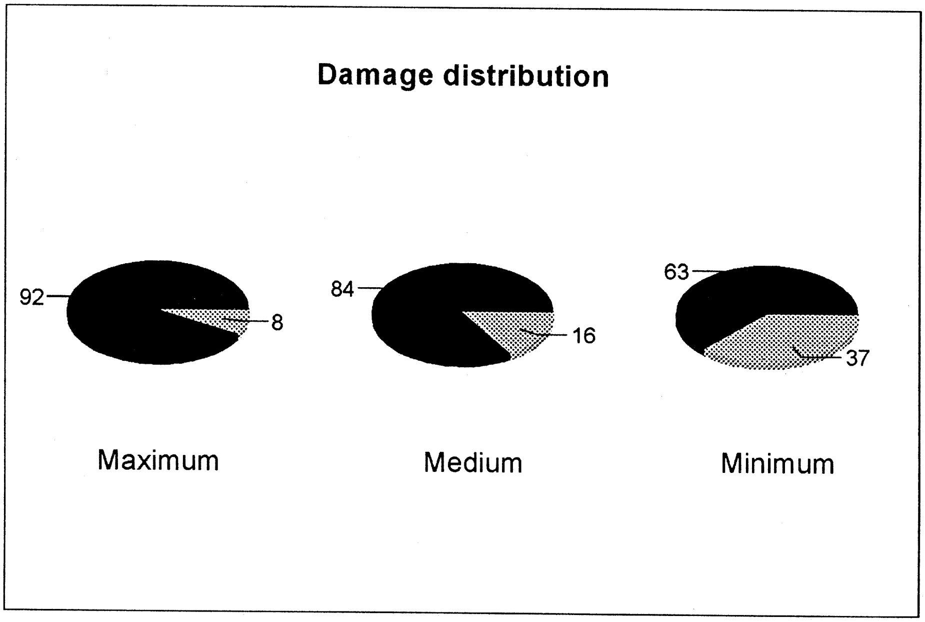

Fig. 8. Distribution of damage in the historical center of Rome in relation to the lithology. Black: percentage of damage to buildings on soft Holocene deposits; gray: damage to buildings on other lithologies.

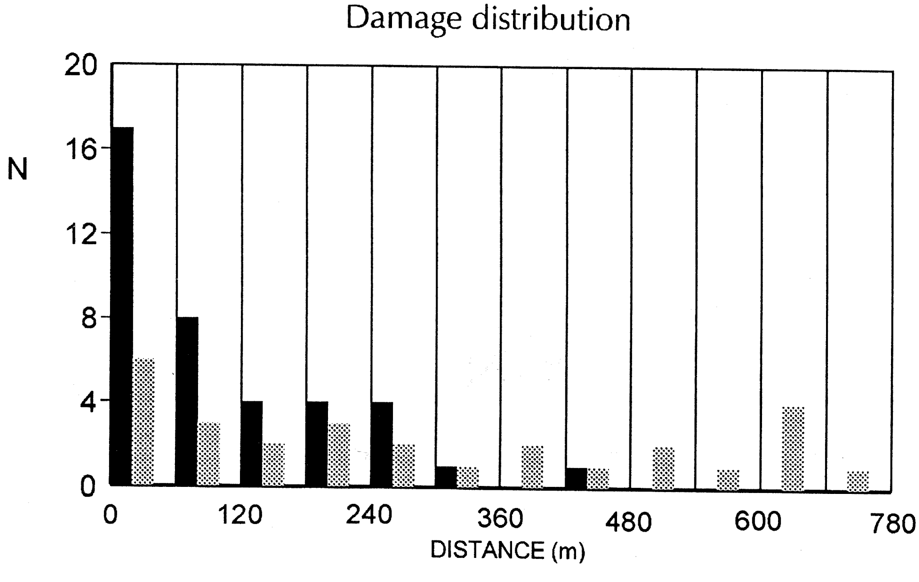

Fig. 9. Number of maximum and medium damage suffered by buildings in the Tiber valley as a function of their location in the valley. Distance is measured from the 20 m isopach of the alluvial deposits projected onto the free-surface. Black bars indicate damage on the right-hand flank of the valley while gray bars indicate for damage on the left-hand flank.

If we then consider the whole set (1895, 1909 and 1915 events) of damage data, we note that the largest percentage for each class is found in areas underlain by Holocene alluvial deposits (fig. 8).

Analyzing the damage distribution in relation to the underground geometry yields further insights into the link between geology and ground shaking. Subsequently we merged the data regarding both medium and heavy damage caused by the above mentioned local and remote earthquakes. Figure 9 groups damage to buildings on both sides of the valley in ranges of 60 m starting from the 20 m isopach of the alluvial sediments. The plot shows different trends for the two sides of the Tiber River valley: on the right-hand side (black) we observe the largest concentration of damage, while on the opposite side the damage is rather scattered.

3. Conclusions

Although Rome was settled in a low seismicity area, it may still suffer earthquake damage particularly in its historical center, that was built on the alluvial sediments of the Tiber River valley. During the past one hundred years Rome has experienced shaking due to local earthquakes, with a maximum intensity of VII MCS, and external earthquakes, reaching similar intensity.

The local seismicity is well constrained within three different areas in the urban and suburban areas of Rome (see table I). Riguzzi and Tertulliani (1993) contended that the epicenter of the 1895 earthquake could not be located offshore near Fiumicino, as suggested in previous studies (Molin *et al.*, 1986; Tacchini, 1895).

Concerning the local response, we emphasize the role of the shallow geological structure in the amplification of the ground shaking and in the generation of complicated damage patterns. Recent studies of the seismic response of Rome (Boschi *et al.*, 1989; Funiciello *et al.*, 1992; Iodice *et al.*, 1992; Rovelli *et al.*, 1994) performed through modeling of the ground shaking produced by the 1915 Avezzano earthquake show the influence that the alternation of soft Holocene deposits of the Tiber River with the more rigid Pliocene bedrock has in the generation of anomalous amplifications. In particular, Rovelli *et al.* (1994) showed that the largest ground motion amplifications are due to the irregularity of the topographic profile on the left-hand side of the valley and to the sharpness of the Pliocene-Holocene interface on the right-hand side. In this paper, the damage distribution produced by local events is compared with the underground geometry of the city of Rome, and this comparison confirms the above mentioned theoretical approaches.

The distribution shown in fig. 9 indeed shows a concentration of damage corresponding with the sharpest portion of the lithological interface. An increase in damage in relation to the shape and thickness of the alluvial beds had already been recognized by Brambati *et al.* (1980) and Yuan *et al.* (1992) for deposits in the thickness range 10-40 m. Hence it is not coincidental that the greatest damage caused by the 1895, 1909 and 1915 events is mainly concentrated on the right-hand side of the alluvial valley within about 300 m from the 20 m isopach of Holocene sediments.

In conclusion, our results show that the inclination of the shallow lithological discontinuities may be responsible for complicated damage patterns, and that damage appears to increase wherever the thickness of the soft alluvial sediments changes sharply in the range 0-40 m. The effects presented here on the city of Rome and particularly on its historical center clearly show how the local effect predominates over the source effect in shaping up the damage pattern.

NOTE IN PROOF

On June 12, 1995, an earthquake shaked Rome at 18.13 GMT ($Md = 3.8$, $I_0 =$ VI MCS), provoking light damage. The epicentre was located in the southern part of the urban area (Lat. = 42.81N Long. = 12.51E, ING preliminary location). The occurrence of such event supports our thesis, according to which the southern neighbourhood of Rome is source of a minor seismicity. Now the June 12, 1995 earthquake location is the first available for this zone from instrumental data. The epicentre lies within the maximum intensity area of the 1895 event as reconstructed by Riguzzi and Tertulliani (1993). This new evidence leads us to strengthen what is emerged from this paper about the seismic hazard of Rome.

Acknowledgements

We wish to acknowledge D. Molin and A. Rovelli for their helpful comments and suggestions. We also wish to acknowledge C. Gasparini for his contribution in the historical research.

Special thanks are due to O. Evandri of Dept. Idraulica, Trasporti e Strade, Area Topografia (University of Rome «La Sapienza») for making available the maps of Rome's urbanization.

REFERENCES

AGAMENNONE, G. (1922): Il terremoto di Castel Romano del 12 Febbraio 1919, *Reale Osservatorio di Rocca di Papa*, Rome.

AMATO, A., C. CHIARABBA, M. COCCO, M. DI BONA and G. SELVAGGI (1994): The 1989-1990 seismic swarm in the Alban Hills volcanic area, Central Italy, *J. Volc. Geoth. Res.*, **61**, 225-237.

AMBROSINI, S., S. CASTENETTO, F. CEVOLANI, E. DI LORETO, R. FUNICIELLO, L. LIPERI and D. MOLIN (1986): Risposta sismica dell'area urbana di Roma in occasione del terremoto del Fucino del 13 Gennaio 1915, *Mem. Soc. Geol. Ital.*, **35**, 445-452.

BOSCHI, E., M. FEROCI, R. FUNICIELLO, L. MALAGNINI, A. ROVELLI and S. SALVI (1989): Valutazione della risposta sismica in ambiente urbano: risultati per la città di Roma, in *Proceedings 8° Annual Meeting GNGTS, Rome*, 317-326.

BOSCHI, E., R. FUNICIELLO, L. MALAGNINI, F. MARRA, A. ROVELLI and S. SALVI (1993): Assetto geologico delle unità plio-quaternarie e risposta sismica nell'area romana, in *Ricerche nel Campo della Sismologia e Geodinamica negli Anni 1990-1991*, Istituto Nazionale di Geofisica, Rome, 317-326.

BRAMBATI, A., E. FACCIOLI., G.B. CARULLI, F. CUCCHI, R. ONOFRI, S. STEFANINI and F. ULCIGRAI (1980): *Studio di Microzonazione Sismica dell'Area di Tarcento (Friuli)*, Clued, Trieste.

DE PANFILIS, M. (1970): Sull'attività sismica nella zona di Ponte Galeria (Roma), *Publication of the Istituto Nazionale di Geofisica*, Rome.

FUNICIELLO, R., E. BOSCHI, M. DI BONA, L. MALAGNINI, F. MARRA, A. ROVELLI and S. SALVI (1992): Local seismic amplifications in the city of Rome inferred from observations of damage in monuments of Imperial age: ground motion estimates based on subsurface geology data, in *Proceedings of the International Symposium on the Effects of Surface Geology on Seismic Motion*, Odawara, Japan, 341-346.

GASPARINI, C., V. DE RUBEIS and A. TERTULLIANI (1992): Method for the analysis of macroseismic questionnaires, *Natural Hazards*, **5**, 169-177.

IODICE, C., D. FÄH, P. SUHADOLC and G.F. PANZA (1992): Un metodo generale per la zonazione sismica immediata ed accurata di grandi metropoli: applicazione alla città di Roma, *Rend. Fis. Acc. Lincei*, **3**, in press.

ISTITUTO GEOGRAFICO MILITARE (1907-1908): Piano topografico di Roma e suburbio alla scala di 1:5000, Rome.

MARTINELLI, G. (1913): Il terremoto romano del 31 agosto 1909, *Boll. Soc. Sismol. Ital.*, **17**, 3-11.

MOLIN, D., S. AMBROSINI, S. CASTENETTO, E. DI LORETO, E. LIPARI and A. PACIELLO (1986): Aspetti della sismicità storica di Roma, *Mem. Soc. Geol. Ital.*, **35**, 439-448.

MOLIN, D. and E. GUIDOBONI (1989): Effetto fonti e effetto monumenti a Roma: i terremoti dall'antichità a oggi, in *I terremoti prima del Mille in Italia e nell'area Mediterranea. Storia archeologia sismologia*, edited by E. GUIDOBONI (SGA, Bologna), 194-223.

RIGUZZI, F. and A. TERTULLIANI (1992): I terremoti romani del 1895 e del 1909, *Geol. Tecn. Ambient.*, **3**, 39-44.

RIGUZZI, F. and A. TERTULLIANI (1993): Re-evaluation of minor events: the examples of the 1895 and 1909 Rome earthquakes, *Natural Hazards*, **7**, 219-235.

ROVELLI, A., A. CASERTA, L. MALAGNINI and F. MARRA (1994): Assessment of potential strong ground motions in the city of Rome, *Annali di Geofisica*, **37**, 1745-1769.

TACCHINI, P. (1895): Terremoto di Roma del 1 Novembre 1895, *Boll. Soc. Sismol. Ital.*, **1**, 203-211.

YUAN, Y., B. YANG and S. HUANG (1992): Damage distribution and estimation of ground motion in Shidian (China) Basin, in *Proceedings of the International Symposium on the Effects of Surface Geology on Seimic Motion*, Odawara, Japan, 281-286.