

Damage scenarios induced by the major seismic events from XV to XIX century in Naples city with particular reference to the seismic response,

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ABSTRACT: The city of Naples, like other towns of large extension, still represents up today a problematic area for the seismic classification of the National Territory. After the 23rd November, 1980 earthquake, the city of Naples was temporarily included in the third seismic category (low seismic zone), waiting for further researches.

In this work a study of the seismic events, that occurred in the Southern Apennine Chain and strongly hit the city, has been carried out in order to analyse the seismic response. In particular it has been conducted a critical comparison of the damages suffered by neapolitan buildings, convents and churches due to strong earthquakes of 1456, 1688, 1694, 1805 and 1980 that hit the city with intensity of VII and VIII degree on the MCS scale. A simple model for the generation of sintetic macroseismic field taking into account the length, the depth of source and the geometrical spreading of S waves, shows that intensity of VII on the MCS scale is the maximum expected level of damages in the city of Naples.

1 BRIEF GEOLOGICAL SETTING OF THE SOUTHERN APENNINES

The structure of the Southern Apennine is the result of a series of tectogenetic events which occurred between the Cretaceous and Pliocene (D'Argenio et al. 1973; Patacca & Scandone 1989). Several tectonic units can be observed in the Southern Apennine. They derive from the deformation of the existing paleogeographic units. The present geological structure has resulted from a process of tectonic shortening, the essentially compressive phases of which started in the lower Miocene and lasted through the upper Pliocene. Then, in the Plio-Quaternary times these units were effected by extensional tectonic.

The Figure 1 shows the structural setting of the southern part of Italy (CNR-PFG 1989) and the ruptures lengths for the major earthquakes. The ruptures were estimated according to Bonilla (1981); the direction of segments is just like the direction of maximum elongation of the isoseisms.

2 LITHOLOGICAL SCHEME OF NAPLES

Based on lithological features, the Naples city territory has been divided in 6 homogeneous areas (AA.VV.,1974; Fig.2).

The area 1 comprises a large part of the urban districts,

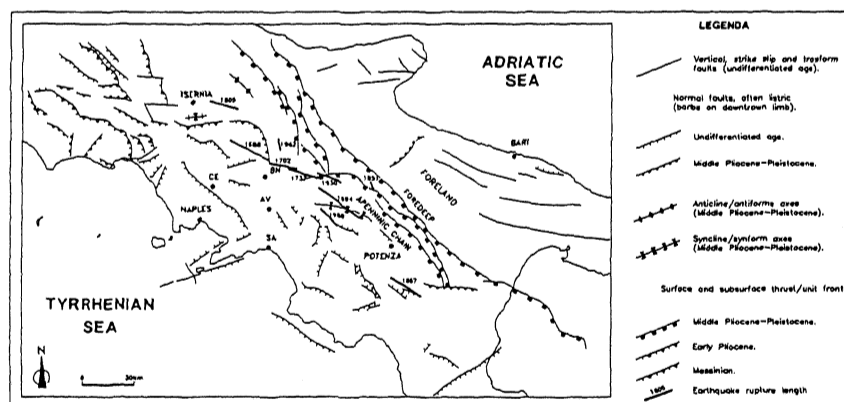


Fig.1 Structural setting of the Southern Apennines. The map shows the rupture lengths for the major earthquakes too. The rupture were calculated according to Bonilla (1981); the segments direction is just like the direction of maximum elongation of the isoseisms. (after CNR-PFG 1989, modified)

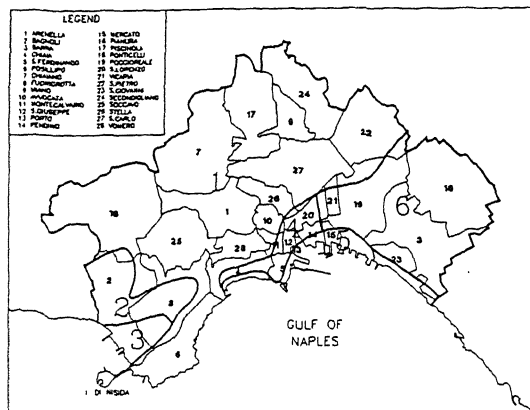


Fig.2 Lithological map of the city of Naples. Based on geological and geotechnical analysis, 6 homogeneous areas have been found (after AA.VV., 1974).

Pianura (16), Vomero (28), Secondigliano (24), S. Pietro (22). It is characterized by the presence of volcanic tuff at a depth of 0-60 m. On its top the tuff is covered by cohesionless pyroclastic rocks (pozzolane) with interbedded pumices.

Urban settlement in this area developed during the XX century excepted for the districts (10) and (26) that were settled before.

-The area 2 includes part of the districts of Fuorigrotta (8) and Bagnoli (2) and it is constituted by cohesionless soft rocks (pozzolane and pumices) having thickness reaching 110 m, and covering the volcanic tuff. Urban development in this area began after 1945.

-The area 3 includes the remaining part of the districts of Bagnoli (2) and Fuorigrotta (8) and is constituted of cohesionless volcanic rocks (pozzolane, pumices) mixed with alluvial rocks. The urban development in this area began after 1945.

-The area 4 includes the historical centre of the town (11,12, 13, 14, 20) and is constituted by the thick yellow tuff (Formazione del Tufo Giallo) lying at a depth between 0 - 20 m under the topographical surface. The urban development in this area is very old as witnessed by the rests of the greek-roman town and by the presence of the monumental buildings ranging in age from XII to XX century.

-The area 5 includes the urban districts of Chiaia (4), S. Giovanni a Teduccio (23), S. Ferdinando (5), Porto (13), Pendino (14) and Mercato (15). This area is mainly composed by filling layer with thickness of the order of metres. This material covers a coastal sandy unit. From Mergellina to Granili (19) the tuff rock follows at a depth of 20-30 m thinning itself approaching the Granili area.

The urban development of this area started in the XIX century.

-The area 6 extends from the districts of Barra (3), Vicaria (21), Poggioreale (19), S. Giovanni (23) to Ponticelli (18).

It is mainly constituted of cohesionless volcanic rocks (pozzolane, pumices, ejecta) mixed to alluvial debris and little lenses of tuff. The urban development in this area starts in the XX century.

The geotechnical features of the lithotypes found in listed areas are gradually worsening with the increase of the identification number given to the identified areas.

3 HISTORICAL SEISMICITY

In the past the seismicity of Southern Italy has been very strong. It was mainly concentrated along the Apennine Chain, with an average distance of 100 km from Naples.

Four historical earthquakes and the 23rd November 1980 earthquake, have been analyzed in order to evaluate the damage level suffered by the city of Naples.

All the events considered (1456, 1688, 1694, 1805 and 1980) reach, in the epicentral area, the X-XI degree on the MCS scale.

3.1 The December 1456 Southern Italy earthquake

Based on the reconstruction of historical earthquake up to now carried out on all the Italian territory, the event of 1456 seems to be the strongest in terms of extension of the shaken area as well as in terms of the number of deaths.

The last revision of this event (Figliuolo, 1988) shows a macroseismic field from Abruzzo to Basilicata regions. It is taken into account as a result of at least two events occurred in the month of December 1456. The reconstruction of the distribution of the effects is based on a wide documentation; the sources report mainly the description of damages suffered by ecclesiastic buildings and fortifications, with the following type of damages: vaults deeply broken, partial collapse of bell-towers, roofs and walls ruined; total collapse of churches and houses. The most damaged area was the historical center (Fig.3 a & b).

In Naples the intensity reached the VIII degree on the MCS scale (CNR- Atlas, 1985; Figliuolo, 1988).

3.2 The 5th June, 1688 Campania earthquake

This earthquake was disastrous above all for the Benevento's area and in particular for all the centers located on the SW side of the Matese Chain and even the Irpinia was strongly hit. The revision of this earthquake is based on documents contemporary to the event (Serva, 1985). The number of deaths has been evaluated in various ways and it ranges from a minimum of 6000 up to a maximum of 18000. Cerreto Sannita e Civitella Licinio (Benevento district) experienced the major damages with a XI degree of MCS scale. Many superficial effects were recognized too; breaking to the ground, liquefaction and landslides occurred in a large area surrounded by the VII degree line. The city of Naples was strongly hit and the number of deaths was 50, many were the damages that monumental buildings underwent: churches, convents and noble buildings (Fig.4 a & b).

In the city the value of intensity reached the VII-VIII degree on the MCS scale.

3.3 The 8th September, 1694 Campania-Lucania earthquake

The macroseismic reconstruction of the 8th September, 1694 earthquake was carried out by Serva (1985) and was based on a great sort of documents found at the Record Offices and the National Libraries of Naples and Rome, as well as a lot of sources found out by the Libraries of Società Napoletana di Storia Patria and Apostolica Vaticana. The shock of 8th September, hit a large part of the Southern Italy and in particular in the Irpinia area caused great damages.

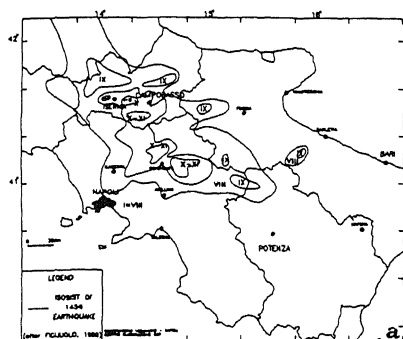


Fig.3 (a) The December 1456 Southern Italy earthquake. The intensity in Naples reached the VIII MCS (Figliuolo 1988). (b) Damages scenario in Naples: the hatched area shows the type of damage suffered by the historical Centre, black colored buildings are the monumental buildings reported into the historical sources. Statistics: 5% great damage with partial collapse; 5% serious damage, deep damage; 90 % slight damage, little damage.

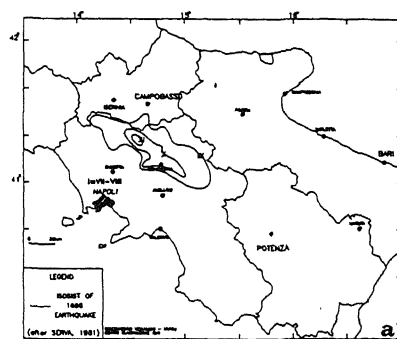


Fig.4 (a) The 5th June, 1688 Campania earthquake. The intensity in Naples reached the VII-VIII MCS (Serva, 1985). (b) Damages scenario in Naples: the hatched area shows the type of damage suffered by the historical Centre, black colored buildings are the monumental buildings reported into the historical documents. Statistics: 3% great damage with partial collapse; 5% serious damage, deep damage; 91 % slight damage, little damage.

Over 6000 people died. About the documents concerning the city of Naples, three contemporary sources to the event were found. All the sources report the descriptions of the damages to the buildings, with particular reference to the ecclesiastical ones. The distribution of damage was rather wide, and the type of effects on the buildings include serious cracks and partial collapses (Fig.5 a & b). In the city of Naples the intensity reached the VII degree on the MCS scale.

3.4 The 26th July, 1805 earthquake

The 26th July, 1805 earthquake mainly hit the Campania and Molise regions. The village of Frosolone (Isernia district) was completely destroyed. The seismic event was felt in a large extension of the Italian territory, the number of deaths was about 6000. The earthquake also produced heavy damage on the environment like deviation of rivers, drying up of springs, landslides and spreading of cracks on the ground. The identification of macroseismic field is

based on the analysis of original documents and contemporary sources found at the Archives and National Libraries (Esposito et al., 1987). The damage scenario of the neapolitan area was very upsetting: in fact many houses were sustained by supports, and many others strongly damaged were demolished. In confirmation of that an edict of the King Ferdinando IV, found at the Borbonic's Archive, tells that the people must remove the ruins of the buildings or to sustain them by supports within four days.

It seems that Quartieri Spagnoli (West part of the city) was the most damaged area of the city, in particular towards the S. Martino Hill. A lot of ecclesiastic buildings suffered very high damage (Fig.6 a & b).

The value of intensity reached by Naples city was VII on the MCS scale.

3.5 The 23rd November, 1980 earthquake

The 23rd November, 1980 earthquake, one of the most violent of the Southern Italy ($I=X$ MSK, $M=6.9$), occurred

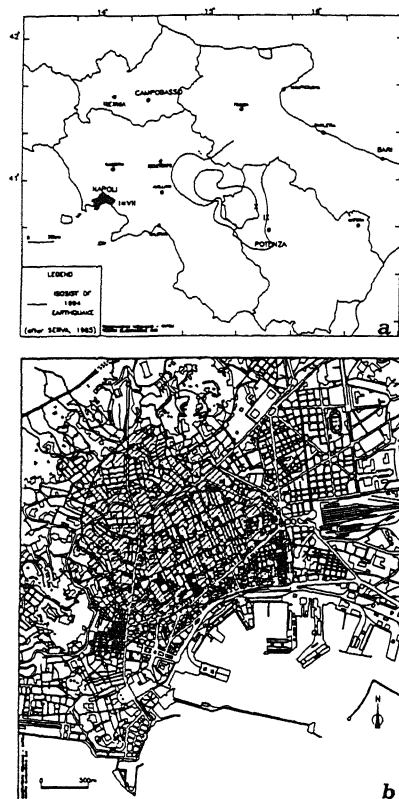


Fig.5 (a) The 8th September, 1694 Campania-Lucania earthquake. The intensity in Naples reached the VII MCS (Serva, 1985). (b) Damages scenario in Naples: the hatched area shows the type of damage suffered by the historical Centre, black colored buildings are the monumental buildings reported into the historical sources. Statistics: 7% serious damage, deep damage; 93 % slight damage, little damage.

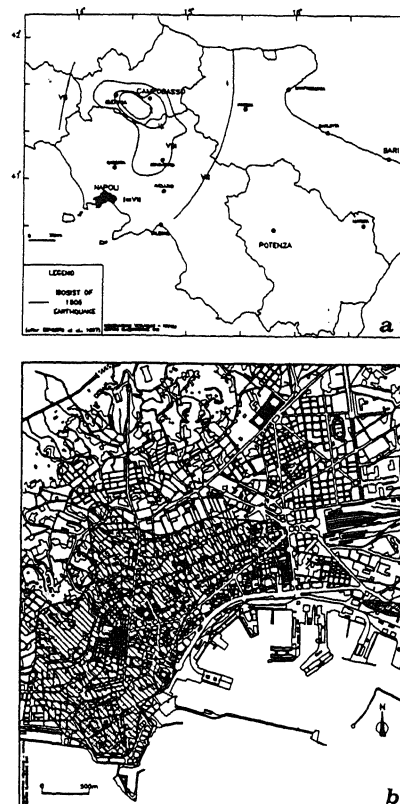


Fig.6 (a) The 26th July, 1805 Molise-Campania earthquake. The intensity in Naples reached the VII MCS (Esposito, 1987). (b) Damages scenario in Naples: the hatched area shows the type of damage suffered by the historical Centre, black colored buildings are the monumental buildings reported into the archives sources. Statistics: 1% great damage with partial collapse; 18% serious damage, deep damage; 81 % slight damage, little damage.

in the Campania - Lucania area. In the town of Naples the intensity reached the VII degree on the MSK scale (Postpischl et al., 1985). The damage suffered by the town was verified through more than 20.000 stability essays on buildings (Rippa & Vinale, 1983), representing 85% of all urban buildings. In the figure 7 (a & b) it is shown the damage degree of the different districts, expressed in per cent of the severely damaged buildings on the total number of urban buildings. Even though in some districts the gathered data are not sufficient for the determination of the damage degree. The same map shows as the greatest damages area constantly placed in the historical centre (20 - 22) and Poggioreale (19). The relationships between the damages and the soil characters become evident as observed that the most severe damages are concentrated in areas with soft foundation rocks.

4 EVALUATION OF LEVEL OF DAMAGES IN THE CITY OF NAPLES USING ATTENUATION LAWS

In order to assess the seismic hazard of the city of Naples

an evaluation of the level of damage provided by the attenuation laws has been performed.

Recent works carried out on the seismic events occurred in the Southern Apennine Chain show that the macroseismic field has a major extension in direction parallel to the Chain. Branno et al. (1986) determined two different functions for the directions parallel and perpendicular to the Chain. Grandori et al. (1991) came to propose a new attenuation law analyzing the isoseismal of 24 earthquakes occurred in Central Italy.

These empirical relations can be successfully employed for a first evaluation of macroseismic intensity.

A simple method for improving the efficiency of the attenuation law can be obtained introducing the geometrical characteristics of the source and of the radiation pattern.

The exact evaluation of the focal mechanisms related to each event requires the use of numerical methods not allowing a parametric analysis of experimental data.

The acceleration field can be considered as a consequence

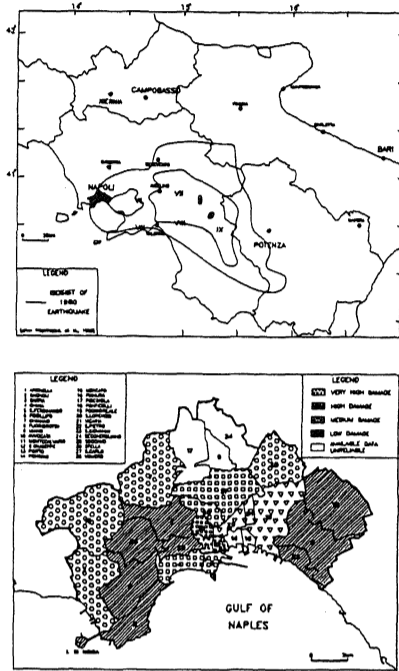


Fig.7 (a) The 23rd November, 1980 Campania-Basilicata earthquake. In the city of Naples the intensity reached the VII MSK scale (Postpischl et al.,1985). (b) Damages scenario in Naples: the figure shows the damage degree of different districts.

of an energy source having finite geometrical dimension(l) and distance z from the surface. The decay of acceleration is proportional to the distance from the source. The radiation pattern of S waves is function of angle θ (Kasahara, 1984) and can be estimated by the following equation (Fig. 8):

$$f(\theta) = 1 + \cos(\theta)^2; \quad [1]$$

Considering the source parallel to the x axis and summing the contribution of the infinitesimal segments of the source, we can write :

$$PGA = \alpha \int_0^l \frac{[1 + \cos(\theta)^2]}{\sqrt{(x-x_p)^2 + y_p^2 + z^2}} dx \quad [2]$$

In which α is the radiation intensity and z the depth of the source, x_p e y_p are the coordinates of a point P locates on the surface.

Integration of equation [2] leads to:

$$PGA = \alpha * 1.25 * \ln \left[\frac{(l-x)}{\sqrt{y_p^2 + z^2}} + \sqrt{\frac{(l-x)^2}{y_p^2 + z^2} + 1} \right] -$$

$$+ \alpha * 1.25 * \ln \left[\frac{-x}{\sqrt{y_p^2 + z^2}} + \sqrt{\frac{x^2}{y_p^2 + z^2} + 1} \right] +$$

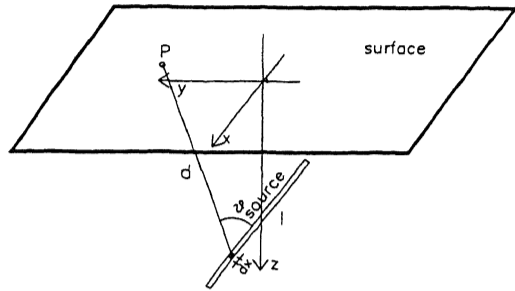


Fig.8 Sketch showing the radiation propagating from an infinitesimal segment(dx) of source. The intensity induced in the point P is proportional to $1/d$ and is function of the angle θ .

$$- \alpha * \frac{\frac{(l-x)}{\sqrt{y_p^2 + z^2}}}{4 * \sqrt{\frac{(l-x)^2}{y_p^2 + z^2} + 1}} + \alpha * \frac{\frac{-x}{\sqrt{y_p^2 + z^2}}}{4 * \sqrt{\frac{x^2}{y_p^2 + z^2} + 1}} \quad [3]$$

The relation between PGA (peak ground acceleration) and macroseismic intensity can be expressed by the following equation (Trifunac & Brady, 1975):

$$PGA(\text{cm/sec}^2) = 50 * 2^{(I-6)} \quad [4]$$

Substitution of eq.[4] in eq.[3] gives :

$$I = \log_2 \left\{ \frac{\alpha}{50} * 1.25 * \ln \left[\frac{(l-x)}{\sqrt{y_p^2 + z^2}} + \sqrt{\frac{(l-x)^2}{y_p^2 + z^2} + 1} \right] - \right.$$

$$+ \frac{\alpha}{50} * 1.25 * \ln \left[\frac{-x}{\sqrt{y_p^2 + z^2}} + \sqrt{\frac{x^2}{y_p^2 + z^2} + 1} \right] +$$

$$\left. - \frac{\alpha}{50} * \frac{\frac{(l-x)}{\sqrt{y_p^2 + z^2}}}{4 * \sqrt{\frac{(l-x)^2}{y_p^2 + z^2} + 1}} + \frac{\alpha}{50} * \frac{\frac{-x}{\sqrt{y_p^2 + z^2}}}{4 * \sqrt{\frac{x^2}{y_p^2 + z^2} + 1}} \right\} + 6 \quad [5]$$

This function differs from the others since it takes into account, in approximate form, the dimension and the depth of source and the diffusion pattern of S waves.

The macroseismic fields obtained from this equation have been compared with the macroseismic fields of the major events occurred in the Southern Apennine Chain, taking into account the length and the orientation of the source.

The length of the source has been evaluated, following Bonilla (1981) :

$$\log(l) = 0.619 * M - 2.77 .$$

The results deriving from the comparison between the theoretical and the experimental macroseismic fields suggest that:

-the value of α results about 500 for all the events and it

has a rather limited scattering;

-the shape of isoseimal lines are very close to the real one near the epicenter. While considering the far field there is a remarkable difference, concentrated always in the same areas, like the Campanian Plain where, systematically, is observed a high level of damage;

-the depth of the source that provides the best fit of the experimental data ranges from 5 to 10 km, as emphasized by Chiaruttini and Siro(1991), Panza et al.(1991) and Sabetta and Pugliese (1987).

Two attenuation functions are represented in Fig.9. Two directions, parallel and perpendicular to the source, have been examined for the different values of the intensity falling into the near field.

Assuming a source depth of about 6 km, the trend of the two functions is in good agreement with experimental data reported by Grandori et al. (1991).

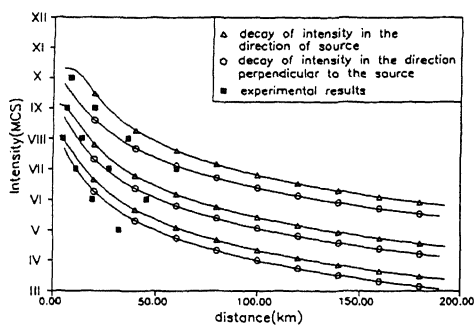


Fig.9 Intensity decay versus epicentral distance calculated with formula [5] compared with experimental results reported by Grandori et. al(1991).

Using the [5] it was possible to simulate the effects of sources having various dimensions, depth, azimuth and located in the seismogenic area of the Apennine Chain. The simulation has emphasized that in any case the level of damage in the city of Naples reaches the VIII degree on the MCS scale.

5 CONCLUSIONS

The historical studies demonstrate that past earthquakes hit the city of Naples with a maximum value of intensity as VIII on the MCS scale. While the analytical model indicates that the maximum value of intensity aspected is limited to VII MCS.

We justify the VIII degree as an amplification due to shallow pyroclastic-alluvial filling of Campanian Plain.

In fact the shape of all the isoseisms, towards Campanian Plain, presents a large area of amplification of the macroseismic effects both for major and smaller events.

Thus distribution of the macroseismic effects observed in Naples seems to be controlled not only by the typology of the affected buildings, but also by the features of the rocks below.

REFERENCES

- AA.VV.(1974). Il sottosuolo di Napoli. AGI VIII Convegno Italiano di Geotecnica. Cagliari. Edizioni Scientifiche Italiane.
- Bonilla, M.G., Mark, R.K., Lienakaemper J.J. 1984. Statistical relations among earthquake magnitude, surface length. *Geology* 6.
- Branno, A., Esposito, E., Luongo, G., Marturano, A., Porfido, S., Rinaldis, V. 1986. The largest earthquakes of the Apennines, Southern Italy. *IAEG Engineering Geology Problems in Seismic Areas*. Vol. IV:3-14.
- Chiaruttini, C. & Siro, L. 1991. Focal mechanism of an earthquake of Baroque age in the "Regno delle Due Sicilie" (Southern Italy). In Stucchi, M., Postpisch, D. & Slejko, D. (Editors), *Investigation of Historical Earthquakes in Europe*. *Tectonophysics*, 193:195-203.
- CNR-PFG 1989. *Syntetic Structural-Kinematic Map of Italy*. Roma.
- D'Argenio, B., Pescatore, T. & Scandone P. 1973. Schema geologico dell'Appennino Meridionale (Campania-Lucania). *Acc. Naz. Lincei*, n.183.
- Esposito, E., Luongo, G., Marturano, A., Porfido, S. 1987. Il terremoto di S. Anna del 26 luglio 1805. *Soc. Geol. Ital.* 37: 171-191.
- Figliuolo, B. 1988. *Il terremoto del 1456*. Ed. Studi Storici Meridionale.
- Grandori, G., Drei, A., Perrotti, F., Tagliani, A. 1991: Macro seismic intensity versus distance: the case of Central Italy. In Stucchi, M., Postpisch, D. & Slejko, D.(Editors), *Investigation of Historical in Europe Earthquakes*. *Tectonophysics*: 193:165-171.
- Kasahara, M. 1981. *Earthquake mechanics*. Cambridge University Press.
- Panza, G.F., Craglietto, A. & Suhadolc, P. 1991. Source geometry of historical events retrieved by syntetic isoseismal. In Stucchi, M., Postpisch, D. & Slejko, D.(Editors), *Investigation of Historical Earthquakes in Europe*. *Tectonophysics*, 193:195-203.
- Patacca, E., & Scandone, P. 1989. Post-Tortonian mountain building in the Apennines. The role of the passive sinking of a relic lithospheric slab. *Accademia Naz. dei Lincei. The Lithosphere in Italy Advances in Earth Science Research*: 157-176.
- Postpischl, D., Branno, A., Esposito, E., Ferrari, G., Marturano, A., Porfido, S., Rinaldis, V. & Stucchi, M. 1985. The Irpinia earthquakes of November 23, 1980. *Atlas of isoseismal maps of Italian earthquakes*. CNR-PFG. N.114, vol.2A.
- Postpischl, D. (Editor) 1985. *Atlas of isoseismal maps of Italian earthquakes*. CNR-PFG. N.114, vol.2A.
- Rippa, F., & Vinale, F. 1983. Effetti del terremoto del 23 Novembre 1980 sul patrimonio edilizio di Napoli. *A.G.I. XV Convegno Nazionale di Geotecnica*:193-206. Spoleto.
- Sabetta, F. & Pugliese, A. 1987. Attenuation of peak horizontal acceleration and velocity from Italian Strong-motion records. *Bull. Seismol. Soc. Am.*. 77:1419-1513.
- Serva, L. 1985. The earthquake of June 5, 1688 in Campania. *Atlas of isoseismal maps of Italian earthquakes*. CNR-PFG. N.114, vol. 2A.
- Serva, L. 1985. The earthquake of September 8, 1694 in Campania-Lucania. *Atlas of isoseismal maps of Italian earthquakes*. CNR-PFG. N.114, vol. 2A.
- Trifunac, M.D. & Brady, A.G. 1975. On the correlation of seismic intensity scales with the peaks of recorded strong ground motion. *B.S.S.A.*. 65:139-162.