01 May 1981, 9:00 am - 12:00 pm

Engineering Seismology Aspects of the M-6.5, Southern Italy Earthquake of Nov. 23, 1980: A Preliminary Review

E. Faccioli
Politecnico di Milano, Italy

Proceedings: First International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics, April 26 - May 3, 1981, St. Louis, Missouri

Engineering Seismology Aspects of the M-6.5, Southern Italy Earthquake of Nov. 23, 1980: A Preliminary Review

E. Faccioli, Associate Professor
Politecnico di Milano, Italy

SYNOPSIS The paper provides an overview of salient engineering seismology features of the earthquake, which was one of the major seismic catastrophes occurring in Italy in this century. After a short description of the characteristics of the earthquake source and of the historical seismicity of the region, preliminary strong-motion and intensity data are presented. Aspects of geotechnical engineering interest include some large landslides in inhabited areas, and notable cases of correlation between severity of damage and local soil conditions and topography.

MAIN CHARACTERISTICS OF THE EARTHQUAKE

The earthquake occurring in Southern Italy on November 23, 1980 at 18 : 34 GMT was one of the most devastating seismic events affecting the country in this century, both in terms of lives lost (close to 3,000, according to official government estimates) and of property damage. Although accurate figures are not yet available, current estimates put the overall damage cost at more than 15,000 million dollars, including indirect damage associated with disruption or slowing down of manufacturing activities (Corriere della Sera, 1981). This amounts to nearly 5% of Italy's GNP for 1980 and is more than 3 times as much as the damage caused by the 1976 Friuli earthquake, which had a magnitude of 6.3. In terms of life loss, the event was overcome in this century only by the great Messina earthquake of 1908 (75,000 victims) and by that of Avezzano, in Central Italy, of 1915 (30,000 victims). Similar to 1908 and 1915, and in spite of the technical knowledge and experience acquired in the meantime, the majority of deaths in the 1980 event was caused by the collapse of old stone-masonry buildings, totally inadequate to withstand the action of seismic loads.
The epicenter of the earthquake was accurately located by means of 14 seismological stations operating within 200 km distance. Preliminary hypocentral parameters are as follows (CNR, 1981a; all seismological information in the sequel is from this reference):

- latitude 40^{o} 46' N
- longitude 15^{o} 18' E
- focal depth 18 km
- Richter magnitude M = 6.5 (TRI)

The epicentral location is shown in Fig. 1.

A preliminary fault-plane solution shows a predominantly dip-slip mechanism; the azimuth of the probable rupture plane is N 120^{o} E, i.e. roughly parallel to the axis of the Apennines. Epicentral isoseismals of the largest historical earthquakes in this area are markedly elongated in the same direction (De Vivo et al., 1979).

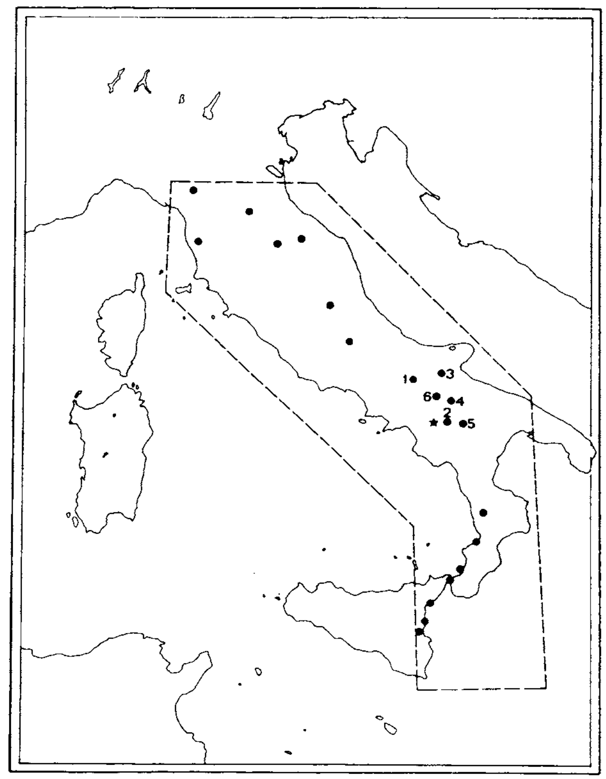

Fig. 1. Epicenters of the largest 1670-1970 earthquakes (M ≥ 6) occurring between Northern Apennines and Eastern Sicily. The epicenter of the 1980 event is shown by the asterisk; for the numbered events see Table I.

The rupture process was in all likelihood a multiple one, with a stronger second event following the first after 2 sec and having a location consistent with a rupture velocity of about 3 km/sec. Also, the area with highest density of aftershocks (Fig. 3) extends over 25 ÷30 km in a SE-NW direction, most of the aftershocks being located to the NW of the main event and having depths between 10 and 20 km. Preliminary estimates of total duration of rupture are between 10 and 15 sec. On the whole, these data suggest that the size of the ruptured zone was rather large for an $M_L = 6.5$ event.

The earthquake took place in an area characterized by intense and well documented historical seismicity. Figure 1 shows the location of all earthquakes with magnitude greater than 6 occurring between Northern Apennines and Eastern Sicily in a period of 300 years (1670-1970). Table I summarizes the epicentral data of historical events closest to the November 23, 1980 epicenter.

Of special interest is the 1694 earthquake which caused widespread destruction and large number of deaths in many of the same settlements as the event under analysis (Baratta, 1901). This is clearly illustrated by the partial overlapping of isoseismal lines of the two earthquakes, shown in Fig. 2. The 1694 earthquake data are from an extensive study carried out by CNEN, to be published very soon.

TABLE I. Epicentral data of the strongest Southern Apennines earthquakes, 1670-1970

Event number (°)	Year	Intensity (MCS scale)	Magnitude
1	1688	X	6+
2	1694	X	6+
3	1731	X	6+
4	1851	X	6+
5	1857	X	6+
6	1930	X	6.5

(°) See Figure 1

Despite the severity of the historical seismicity record, provisions for earthquake resistant design were applicable only in a small number of municipalities of the affected area, which were damaged by an M = 5.8 earthquake occurring in 1962 some 40 km N of the recent epicenter. Among these municipalities, assigned by law to 2nd category seismic zones (+) in 1972, was the small town of S. Angelo dei Lombardi, partly destroyed by the 1980 event (Fig. 2).

A preliminary evaluation of the behavior of reinforced concrete buildings (mostly 2 to 6 stories high) existing in this town has shown that several structures built after 1972 did not resist the earthquake better than those erected prior to 1972, and some of them actually worse. Aside from the fact that the applicable lateral design coefficient might have been inadequate for very strong ground motions lasting some 10-15 sec, many instances of structural failure and heavy damage were caused by obvious design faults and careless detailing and execution, whereas others were favored by hazardous location. The lesson taught by the earthquake as regards recent buildings, although not a new one, is clear: land use criteria, architectural layout, overall standards of design and execution are at least as important as nominal application of norms to provide acceptable levels of protection against earthquake hazard.

(+) According to Italian seismic norms, the basic lateral design coefficients to be used in 1st and 2nd category zones are 0.10 and 0.075, respectively, for natural vibration periods not exceeding 0.8 sec.

PRELIMINARY STRONG-MOTION AND INTENSITY DATA

Since the completion of Italy's permanent accelerograph network, jointly operated by ENEL (National Electricity Board) and CNEN (Nuclear Energy Commission), this was the best recorded strong earthquake in terms of both the number and the azimuthal distribution of triggered stations.

All of the 15 instruments located within 80 km from the epicenter were triggered, whereas 10 out of a total of 31 located within about 140 km did not trigger. Propagation of energy appears to have been strongest towards NW, probably due to the influence of both regional geology and rupture mechanism, and this may explain the uneven triggering of instruments at the larger distances. Unfortunately no record was obtained within the seismic source zone or in the area of heaviest damage.

Fig. 3 displays on a regional map the largest horizontal acceleration value at each station, directly scaled from copies of the original 70 mm film records (Commissione CNEN - ENEL, 1980).

Table II gives a more complete description of the data for each of the recording stations, including the shortest distance between the rupture surface and the instrument site. Following Boore et al. (1978) the location and size of rupture were inferred from the distribution of dense aftershocks (Fig. 3). Thus, a vertical plane through the epicenter was assumed with an azimuth of N 120° E, a total length of 25 km, and a minimum depth of 10 km, consistent with preliminary seismological evidence.

The strong-motion records basically represent free field motions, since all accelerographs are placed at the ground level of small electrical substation facilities. The most significant portions of the three accelerograms closest to the seismic source are shown in Fig. 4. Note the 1 sec wave at the onset of the strong-motion phase in the E-W component at BI, the station nearest the source and otherwise characterized by relatively low amplitudes and significant duration. The largest acceleration (0.35 g) appears in the ST record, E-W component, about 5.5 sec after triggering and is immediately followed by waves having a period of nearly 3 sec. Since ST had an azimuth of only 20°-30° from rupture direction, source directivity effects might explain the difference in acceleration level with respect to stations located at comparable distances such as BS, CA and AU. Although subsoil conditions at the ST site are unknown, the geological and topogra-

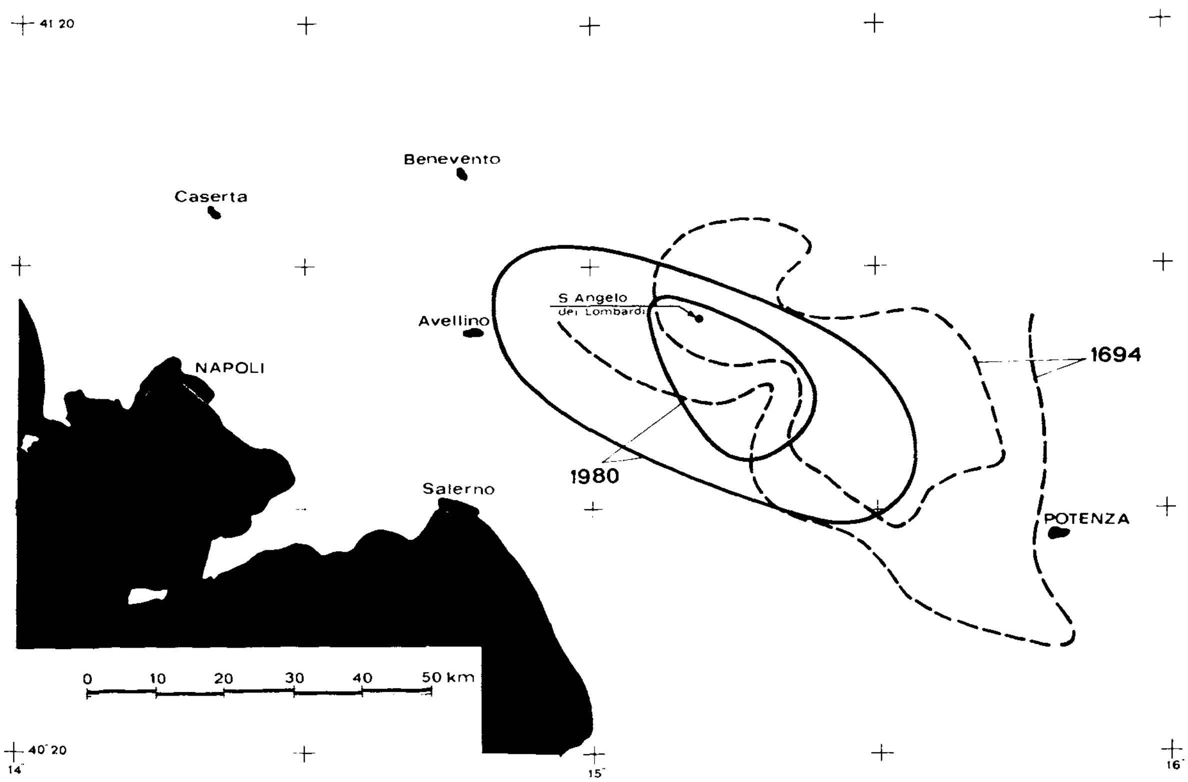

Fig. 2. Isoseismal lines of MCS degrees IX and X of 1694 and 1980 earthquakes

phic context suggests the presence of a relatively thick cover of sedimentary materials. A preliminary pseudo-acceleration response spectrum, calculated from the first 13 sec of the uncorrected ST record, is shown in Fig. 5.

The accelerogram at the bottom of Fig. 4 was recorded very near the top of the hill of Calitri, a rather steep relief rising some 300 m above the nearby Ofanto river; its long duration at a sustained acceleration level of about 0.10 g (more notable in the EW component) might well have been influenced by topography effects. The engineering importance of this record stems from the fact that the accelerograph was only 30 m from the upper edge of a huge landslide activated by the earthquake (see next section). Notable among the other records is a 0.22 g peak value recorded at BR, 38 km from the source and probably caused by local amplification effects.

A plot of the peak horizontal acceleration at each station vs. source distance is given in Fig. 6: also shown for comparison is the 70% prediction interval for M = 6.0 - 6.4 U.S. data recorded at the base of small structures as obtained by Boore et al. (1978). Whereas the distance attenuation rate is roughly similar for the two data sets, accelerations from Western U.S. earthquakes seem to be higher in the 15 to 55 km distance range.

Immediately after the earthquake, a systematic field evaluation of macroseismic intensities was organized, among other things, by the Geodynamics Project of Italy's National Research Council (CNR). Such an evaluation was carried out by multidisciplinary teams, who visited nearly 300 centers in the damaged area over a period of a few weeks. Empirical intensity ratings were made both according to the MCS scale (Fig. 2), traditionally used in Italy in the study of historical earthquakes and especially suited to stone masonry construction, and to the MSK scale, more sensitive to the actual characteristics of ground shaking (CNR, 1981b). The resulting distribution of MSK intensities, duly filtered and smoothed, is illustrated in Fig. 3 together with recorded peak accelerations. Local intensity anomalies, both on the high and low side, were especially frequent and some of them can be seen in Fig. 3. The location of many settlements, or of parts of them, on prominent topographical positions has often caused a substantial increase of local intensity, and so did the presence of poor foundation soils. However, an attempt to correlate recorded accelerations with the intensities observed near the strong-motion stations is virtually meaningless except at far distances. As an example, local MSK intensities of VI were observed at BI and ST, with peak accelerations of 0.19 and 0.35 g, whereas AU had a local intensity of VIII with an acceleration of 0.06 g.

The shape and position of the higher intensity isoseismal lines supports the preliminary characterization of the seismic source (in fact, one might even be tempted to speculate that the small areas with intensity X roughly correspond to the terminal portions of the rupture surface). The areas shaken with $I_{MSK} \geq$ IX and $I_{MSK} \geq$ VIII were of about 450 km^2 and 2500 km^2, respectively.

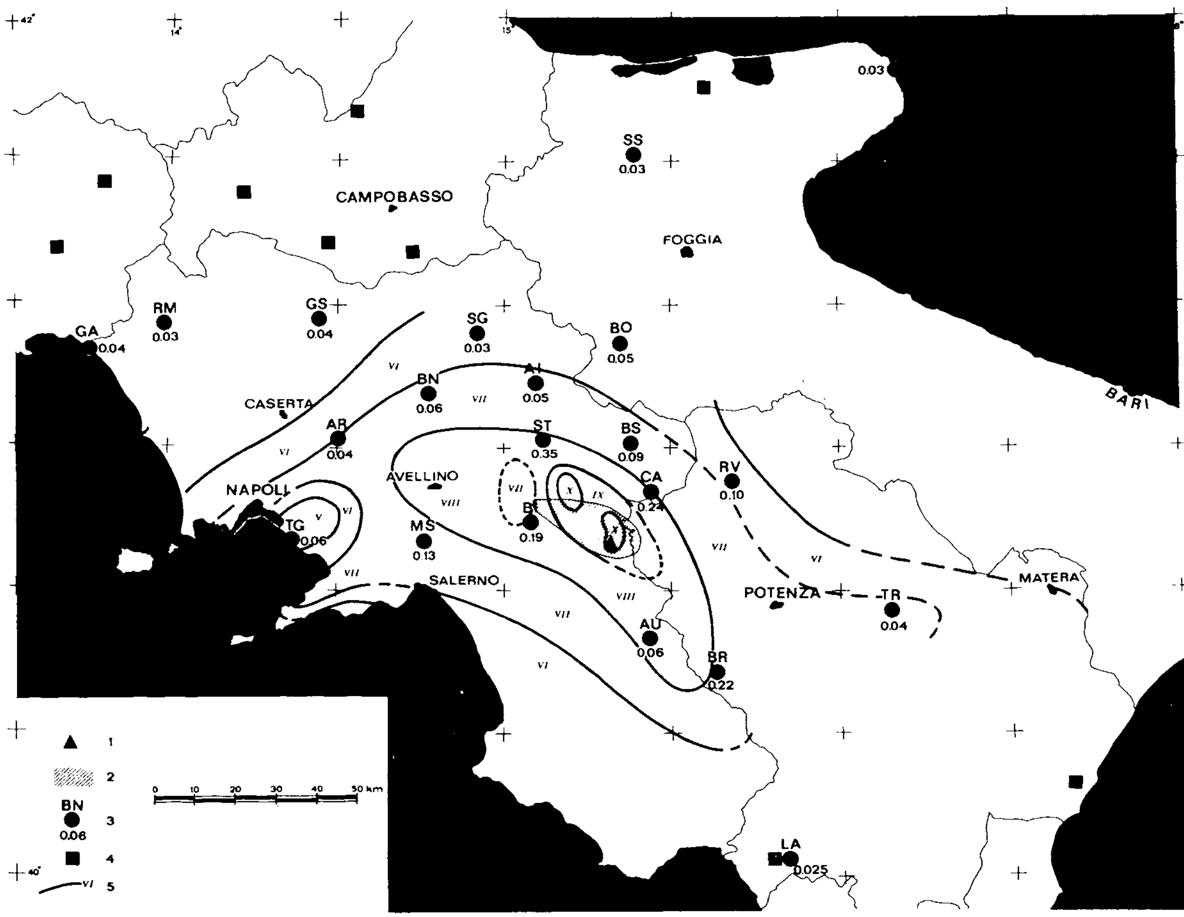

Fig. 3. Main instrumental and intensity data of the 1980 earthquake: 1-epicenter of main shock; 2-area of dense aftershocks; 3-triggered accelerograph and peak horizontal acceleration in g; 4-untriggered accelerograph; 5-isoseismal line and MSK intensity degree

TABLE II. Preliminary strong-motion data

SMA-1 accelerograph station		Epicentral distance (km)	Distance from rupture (km)	PGA (g)		
				NS	Up	EW
Bagnoli I.	(BI)	23	12	0.14	0.11	0.19
Sturno	(ST)	35	18	0.24	0.28	0.35
Calitri	(CA)	18	19	0.11	0.13	0.12
Auletta	(AU)	26	25	0.06	0.04	0.06
Bisaccia	(BS)	28	26	0.09	0.06	0.08
Mercato S.S.	(MS)	48	32	0.11	0.06	0.13
Rionero in V.	(RV)	35	32	0.10	0.07	0.09
Ariano I.	(AI)	48	32	0.04	0.04	0.05
Brienza	(BR)	40	38	0.22	0.18	0.17
Benevento	(BN)	62	40	-	-	0.06
Bovino	(BO)	56	46	0.04	0.04	0.05
S. Giorgio M.	(SG)	67	47	0.03	-	0.03
Arienzo	(AR)	75	53	0.03	0.02	0.04
Torre del G.	(TG)	80	63	0.06	0.03	0.04
Tricarico	(TR)	70	65	0.04	0.03	0.03
Gioia S.	(GS)	95	73	0.04	0.03	0.03
Lauria	(LA)	89	88	0.02	0.01	0.02
S. Severo	(SS)	103	93	0.03	0.02	0.03
Roccamonfina	(RM)	127	103	0.025	-	0.025
Garigliano	(GA)	140	118	0.04	0.03	0.04
Vieste	(VI)	142	140	0.04	0.02	0.04

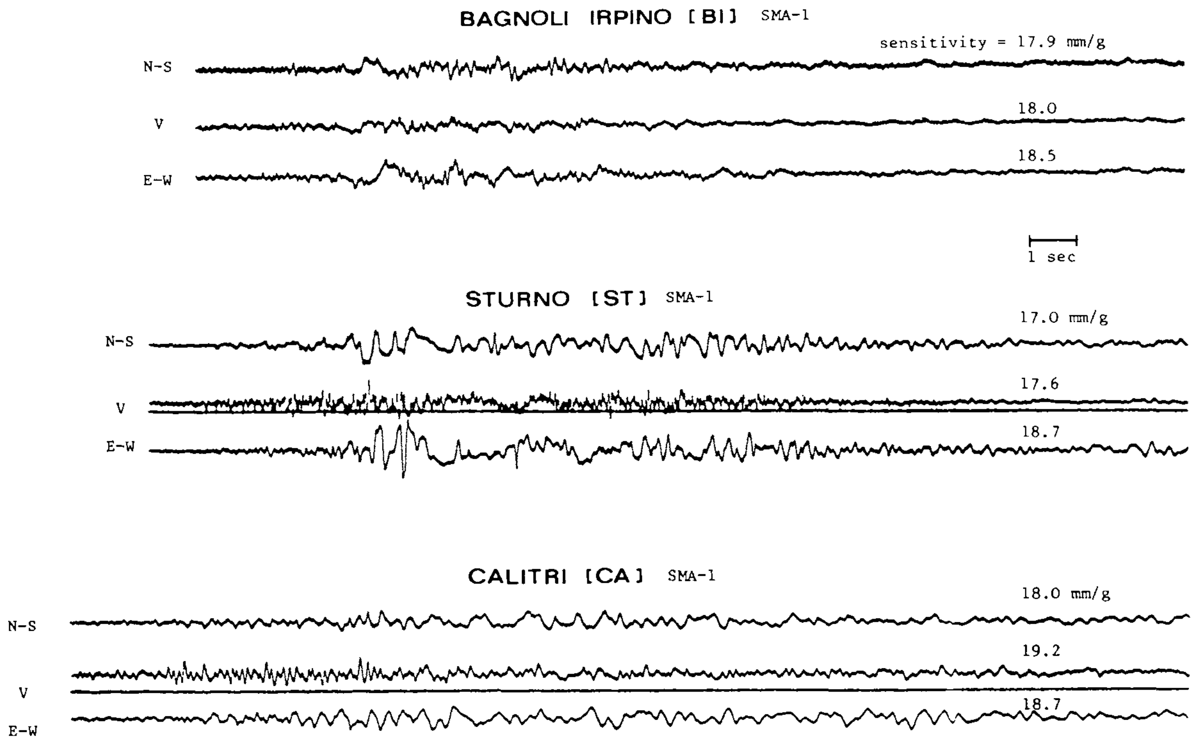

Fig. 4. Strong-motion accelerograms obtained at the stations closest to the source (sensitivities refer to the trace amplitudes in their original size on the 70 mm film records).

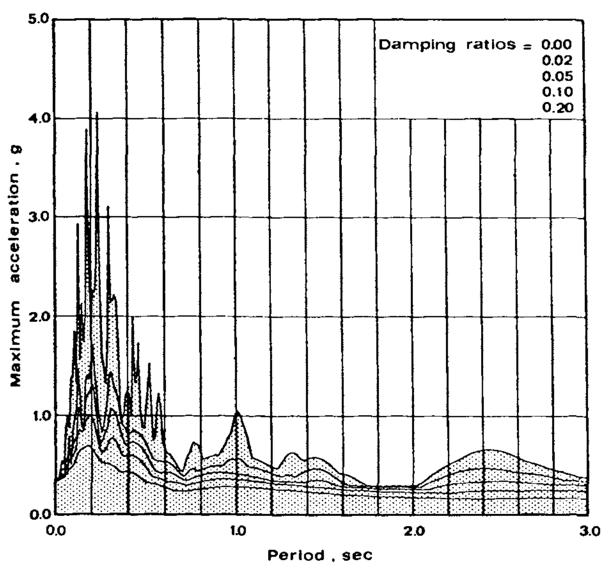

Fig. 5. Preliminary pseudo-acceleration response spectrum of the uncorrected EW component of the Sturno record (from Briseghella and Zaccaria, 1981)

ASPECTS OF GEOTECHNICAL ENGINEERING INTEREST

The near-surface geology and the abrupt changes in relief characterizing most of the Southern Apennines region, including the sites of several centers within or near the epicentral area, have generally favored local seismic effects.

Problems of slope instability in natural soft clay soils and fissured marls have existed since a long time virtually in the whole area, made more acute by the absence of proper land use criteria, continuous emigration of the countryside population into the cities, and insufficient reforestation. The earthquake also reactivated dormant landslides within several population centers, such as Bisaccia, Senerchia, S. Giorgio la Molara, and Calitri, to the extent that they might have to be partially or totally relocated for reconstruction. Of particular engineering relevance is the mentioned landslide in Calitri (CA in Fig. 3), where a permanent vertical displacement of the order of 1 m occurred at the top edge (Fig. 7) and several zones of intense ground deformation have developed (Fig. 8). Part of the most recent town development had taken place in this area, despite previous symptoms of potential instability dating as far back as the 1694 earthquake (Baratta, cit.) and the fact that the enforcement of seismic norms in the municipality since 1972 should have suggested additional caution. The writer also found evidence of limited sand liquefaction phenomena under a 1-story building in the middle of the slide area, but it seems unlikely that liquefaction itself was a major cause of instability since granular quaternary sediments are absent or very scarce.

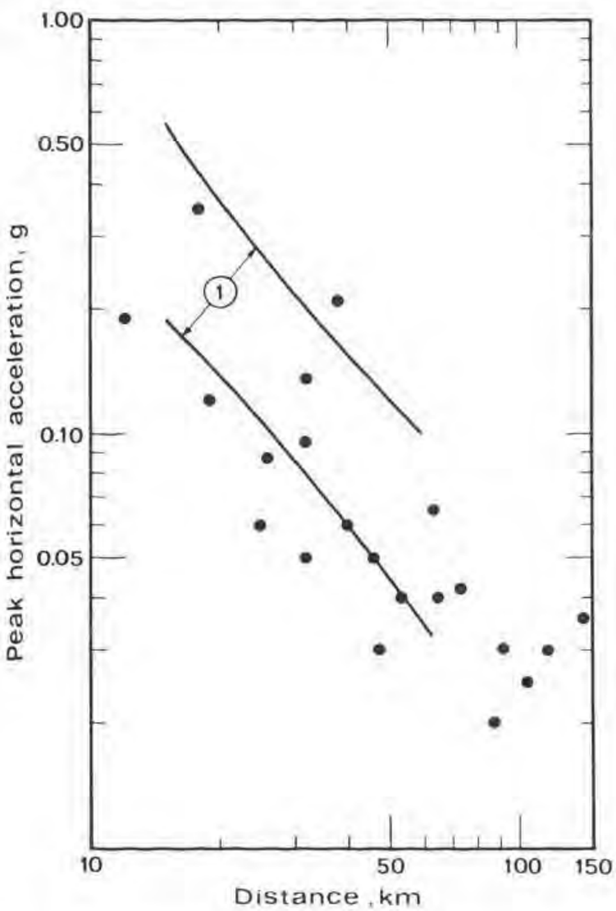

Fig. 6. Attenuation of peak horizontal accelerations vs. shortest distance from rupture surface; 1 : 70% prediction intervals for M = 6.0 - 6.4 U.S. data, from Boore et al. (1978)

The fact that an accelerograph placed only a few m from the site of Fig. 7 produced a good record of the main shock (Fig. 4) and of a strong aftershock, should make the Calitri land slide amenable to quantitative dynamic modeling once the necessary geotechnical data will be acquired.
There was no surface tectonic faulting associated with the earthquake. However, a large number of ground ruptures, ranging in length from a few m to several hundred m, were observed over a territory considerably larger than the epicentral area. A statistical frequency analysis of the orientation of the ruptures shows that their predominant azimuth is roughly the same as that of the probable earthquake source, i.e. N 120° (Scandone, 1981). A segment of one of the most notable among these ruptures, occurring some 15 km SE of the epicenter near S. Gregorio Magno, is illustrated in Fig. 9; here the ground break crosses open farmland as a sharp straight line having a length of the order of 500 m and a predominantly vertical offset of 30-50 cm.

At the time of this writing, several teams of earthquake engineers and geologists operating in the framework of the Geodynamics Project are about to complete a campaign of preliminary microzoning investigations on 25 population centers with MSK intensities from VIII to X. The main goal of this work is to provide local administrations with rational tools for decision making on reconstruction. Such tools basically consist of zoning maps, in scale 1 : 5,000 or 1 : 2,000, where areas having specific geotechnical, geologic and seismic problems are identified, and preliminary recommendations are given concerning land use, remedial measures and level of earthquake design coefficients.

In this context, close associations between near surface geological conditions or topography and local severity of damage have been noted in many instances for stone masonry construction of va-

Fig. 7. Permanent vertical displacement at top edge of the landslide in Calitri

Fig. 8. Zone of intense ground deformation caused by the landslide in Calitri

Fig. 9. Segment of earthquake induced ground crack in open farmland near S. Gregorio Magno

riable age and quality, and also for reinforced concrete structures, although to a less extreme degree.

A rather significant example was found in the survey of Muro Lucano, jointly carried out by the author and L. Siro as a geologist.

Muro Lucano is a center of some 8,000 people, which had preserved almost intact a peculiar urban structure and landscape through the centuries; it was located some 20 km E of the epicenter and suffered an MSK intensity of VIII. The picture of Fig. 10 shows the historical part of the town, composed in its totality of stone-masonry buildings 2 to 4 stories high, many of them 200 or 300 years old. It rises on a limestone ridge, abruptly cut on the back side by a cliff of about 150 m. Whereas most of the buildings seen in Fig. 10 suffered light to medium damage, a concentration of collapsed or heavily damaged dwellings occurs on a fairly narrow zone running from top left to bottom center of the picture, which could not be explained by any significant difference in the type or quality of construction. The geological survey revealed that the stripe of severe damage coincides with an isolated cover of loose breccia only a few m thick, locally overlying the limestone (Fig. 11). Since the only foundation support of the buildings is provided by the main walls penetrating to very shallow depth into the loose materials, the effects of earthquake ground shaking were apparently much stronger than on adjacent rock. The other cases of collapse shown on top left and center right of Fig. 11 were due to an entirely diffent cause, namely the opening or reactivation of fissures in the rock mass, certainly favored by the location on prominent crests only 10 to 15 m wide.

The example of Muro Lucano, although by no means an extreme one in terms of damage intensity, is apt to give an idea of some of the problems facing reconstruction in this region, where adverse geomorphological conditions and the need to preserve complex and often beautiful historical realities go hand by hand and represent the rule rather than an exception.

AKNOWLEDGEMENTS

The support of the National Research Council's (CNR) Geodynamics Project, which sponsored and organized most of post-earthquake research work in seismology geology and engineering, is gratefully aknowledged. Thanks are also due to Mr. F. Capozza, secretary of the joint ENEL-CNEN Commission, for making copies of the original strong-motion records timely available.
Paper no.413 of the Geodynamics Project series.

REFERENCES

Baratta, M. (1901), "I terremoti d'Italia", Fratelli Bocca Editore, Turin, Italy.

Boore, D. et al. (1978), "Estimation of ground motion parameters", U.S. Geological Survey Circular 795.

Briseghella, L. and P. Zaccaria (1981) "Terremoto dell'Irpinia 1980: rapporto preliminare", Istituto di Scienza delle Costruzioni, Università di Padova, Padua, Italy.

Commissione CNEN-ENEL (1980), "Terremoto campano lucano del 23 novembre 1980. Prime registrazioni della rete di stazioni accelerometriche fisse e mobili dell'ENEL e del CNEN", Rome, December.

CNR (1981a), "Il terremoto campano-lucano del 23/11/80: elaborazione preliminare dei dati sismometrici", presented by Gruppo di Lavoro Sismometria at Convegno Straordinario Progetto Finalizzato Geodinamica, Rome, 27-28 January.

CNR (1981b), "Il terremoto del 23/11/80, rilievo macrosismico: stato di avanzamento al 27/1/81", presented by Gruppo di Lavoro Macrosismica at Convegno Straordinario Progetto Finalizzato Geodinamica, Rome, 27-28 January.

Corriere della Sera (1981), weekly economic supplement, March 12.

De Vivo, B. et al. (1979), "Carta sismotettonica preliminare dell'Appennino Meridionale", Paper No. 166, Progetto Finalizzato Geodinamica,CNR, Rome.

Scandone, P. (1981), personal communication.

Fig. 10. View of the old section of Muro Lucano. Note stripe of heavy damage running from top left to bottom center of the picture.

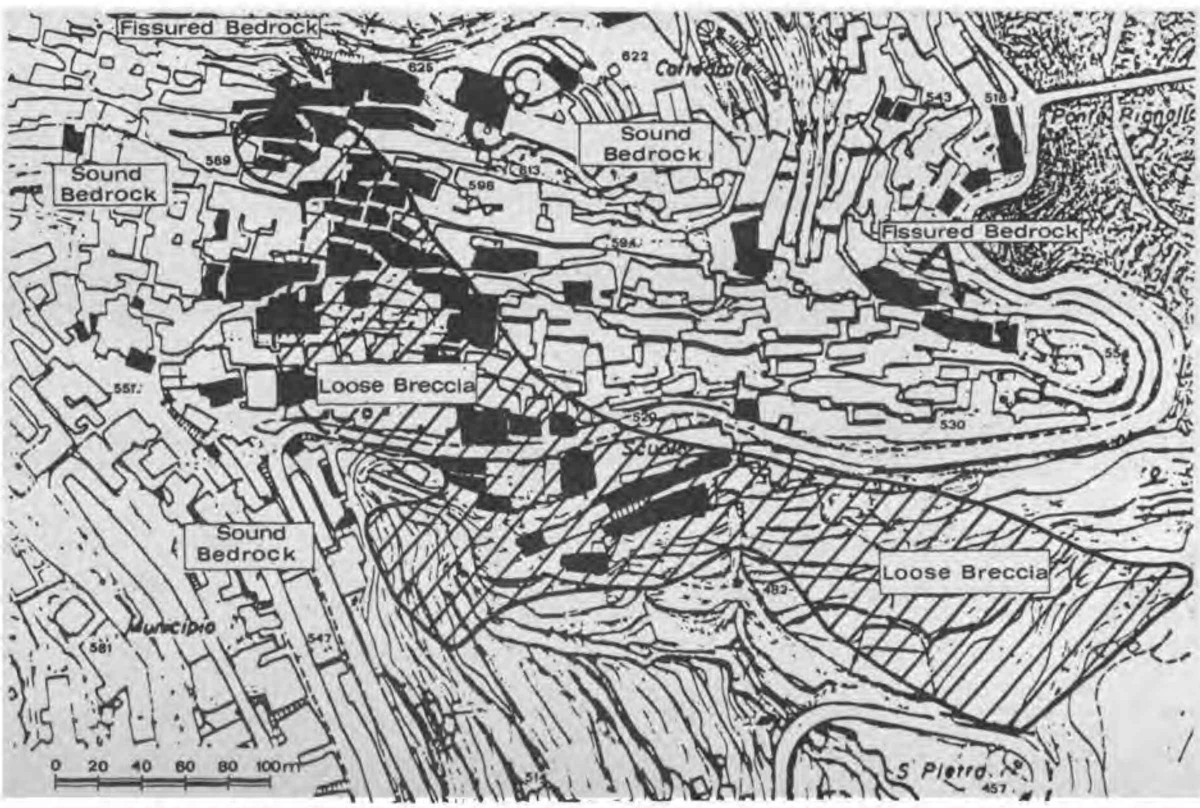

Fig. 11. Plan view of the Muro Lucano section shown in Fig. 10, with surface geology and elevations in m. Collapsed or heavily damaged dwellings are darkened;the hatched area denotes local cover of loose breccia.