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THE AIGIO (GREECE) SEISMIC SEQUENCE OF JUNE 1995: SEISMOLOGICAL, STRONG MOTION DATA AND EFFECTS OF THE EARTHQUAKES ON STRUCTURES

V. A. LEKIDIS*, C. Z. KARAKOSTAS*, P. P. DIMITRIU*, B. N. MARGARIS*,
I. KALOGERAS† and N. THEODULIDIS*

**Institute of Engineering Seismology and Earthquake Engineering (ITSAK),*
P.O. Box 53, GR 551 02 Finikas, Thessaloniki, Greece
†Geodynamic Institute of the National Observatory of Athens,
P.O. Box 20048, GR 118 10 Lofos Nimfon, Athens, Greece

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On 15 June 1995, an earthquake of moment magnitude $M_w = 6.4$ occurred in the western part of Corinthiakos Gulf, Greece, causing the loss of 26 human lives and inflicting considerable damage mainly in the northern part of Peloponnessus. Particularly damaged was the town of Aigio with its environs. The only strong motion instrument in operation at the time of the mainshock in the town of Aigio recorded a horizontal acceleration as high as 0.54 g — the highest ever recorded in Greece — in the vicinity of a collapsed building. The main characteristic of the recorded strong ground motion is the pulse-like shape of its most intensive part, with a period of about 0.45 sec. The macroseismic observations are in good agreement with the distribution of the peak horizontal acceleration — recorded at epicentral distances from 18 km to 78 km, and both sets of data imply anisotropic radiation of seismic waves by the source. The tremor and its largest aftershock ($M_w = 5.6$), which followed about 15 minutes later, caused total or partial collapse of a few buildings and heavily damaged several more. However, despite the very high recorded accelerations — the highest recorded in Greece — and the highest response spectra resulting from them, damage was not as much as one might have expected, considering the poor earthquake design and construction practices under which the majority of the buildings in the town and its surroundings had been built. This earthquake demonstrated among others, the great improvement in seismic behaviour of buildings effected by the application of the revised Greek Seismic Design Code of 1984, along with the importance of strength reserves of existing buildings in alleviating the consequences of strong ground motions.

Keywords: ground acceleration, directivity, seismic response of structures, code provisions, structural damage, ductility demands.

1. Introduction

On 15 June 1995, 00:15 GMT, a moment magnitude $M_w = 6.4$ earthquake shook an area including the town of Aigio and nearby villages in western Corinthiakos Gulf, Greece. The tremor killed 26 people and caused extensive destruction mainly in the central part of Aigio and lesser damage in its environs and other locations on both shores of the gulf. The strongest aftershock $M_w = 5.6$ occurred at 00:31 GMT, and intense seismic activity lasted for several weeks.

The mainshock, the largest aftershock, and the subsequent seismic activity were recorded by instruments of the National Seismological Network, run by the Geodynamic Institute of the National Observatory of Athens (GI-NOA) and the Seismological Network of the Aristotle University of Thessaloniki. During the days following the mainshock, GI-NOA deployed in the area another four portable seismographs, which recorded the post-event activity for 15 days. An additional number of portable seismic instruments were installed in the framework of a common French–Greek project, in order to monitor the aftershock activity [Bernard *et al.*, 1997]. The seismic activity of the period May–July 1995 (events with $M_w \geq 3.5$) is listed in Table 1 and is shown in Fig. 1 together with smaller shocks. The record-

Table 1. Seismic activity of the Aigio seismic sequence 1995. Data derived from permanent seismological stations with $M_w > 4.0$ and from Local Network with $M_w > 3.5$ [Karakostas *et al.*, 1997].

Date	Time		Lat.	Long.	Dep.	M_w
950508	511	7.27	38.335	22.182	7.8	4.5
950528	1956	40.03	38.387	22.005	6.8	4.6
950615	015	49.09	38.362	22.227	11.7	6.4
950615	031	1.39	38.353	22.249	10.3	5.6
950615	116	20.78	38.339	22.188	10.3	4.0
950615	121	26.31	38.321	22.129	6.4	3.8
950615	238	6.46	38.334	22.119	5.2	3.7
950615	443	10.89	38.310	22.165	11.1	3.5
950615	451	18.88	38.268	22.216	10.6	4.5
950615	7 0	59.80	38.337	22.124	10.8	4.4
950615	717	37.91	38.274	22.171	12.8	3.7
950615	720	6.91	38.364	22.187	11.7	3.7
950615	822	32.90	38.339	22.130	9.7	3.6
950615	840	23.86	38.272	22.122	10.9	3.6
950615	1041	49.79	38.323	22.178	9.5	4.1
950615	1435	14.70	38.276	22.144	7.1	3.5
950616	3 3	9.46	38.333	22.166	9.6	3.6
950616	727	11.75	38.235	22.123	2.8	3.5
950616	1640	18.31	38.355	22.143	6.5	3.8
950616	1823	10.30	38.348	22.108	7.8	3.7
950616	1846	31.36	38.265	22.165	6.1	3.8
950616	1929	45.29	38.340	22.142	9.9	3.8
950616	2256	0.07	38.345	22.264	10.1	3.5
950617	1111	59.37	38.326	22.176	5.6	3.6

Table 1. (*Continued*)

Date	Time		Lat.	Long.	Dep.	M_w
950617	1120	58.03	38.318	22.185	3.4	3.7
950617	1420	28.62	38.354	22.266	13.2	4.3
950617	1424	27.25	38.352	22.100	4.7	3.5
950617	1454	22.23	38.305	22.200	5.7	3.6
950618	114	5.72	38.359	22.128	8.9	4.2
950618	447	19.07	38.352	22.133	4.9	3.6
950618	452	5.80	38.332	22.115	9.8	3.7
950619	619	17.27	38.293	22.237	5.5	3.9
950620	1438	32.53	38.359	22.103	11.9	4.0
950620	16 7	27.78	38.382	22.116	8.0	3.6
950620	2021	41.74	38.328	22.111	10.2	3.6
950621	1 3	19.38	38.342	22.121	8.9	3.6
950621	224	25.72	38.299	22.156	5.2	3.7
950621	530	21.67	38.370	22.159	8.7	3.8
950621	15 1	5.41	38.377	22.121	8.4	3.8
950622	7 8	27.30	38.392	22.031	7.0	3.6
950624	1316	53.93	38.322	22.157	6.7	3.8
950624	1327	19.57	38.367	22.238	12.5	3.9
950625	242	39.09	38.383	22.242	10.1	3.5
950625	1412	54.37	38.296	22.087	3.0	3.6
950626	152	58.13	38.286	22.045	4.9	3.6
950626	11 0	39.31	38.287	22.027	8.1	3.6
950701	2022	42.60	38.319	22.281	9.9	3.8
950701	2158	4.32	38.308	22.171	6.4	4.1
950704	1352	46.29	38.295	22.052	8.3	4.2
950705	1824	37.18	38.380	22.114	8.2	4.7
950710	1812	38.42	38.444	22.102	11.1	4.5
950715	936	57.97	38.422	22.085	11.4	4.1

ings of the seismological stations of the permanent Greek network in combination with a 3D lithospheric model were used to locate the earthquakes. Both the spatial distribution of the aftershock foci and the fault-plane solutions proposed by NEIC (National Earthquake Information Center, $\varphi = 276°$, $\delta = 34°$, $\lambda = -73°$) and by Harvard University ($\varphi = 287°$, $\delta = 32°$, $\lambda = -78°$) indicate an almost E-W trending, north-dipping normal fault 25 km in length. The focal depths of the earthquakes are in the range of 5–15 km, and the mainshock nucleated at the eastern end of the fault, implying unilateral rupture propagation towards the town of Aigio [Karakostas *et al.*, 1997]. The mainshock fault-plane solution proposed by Harvard University and the location of the analog accelerograph (SMA-1) that recorded the

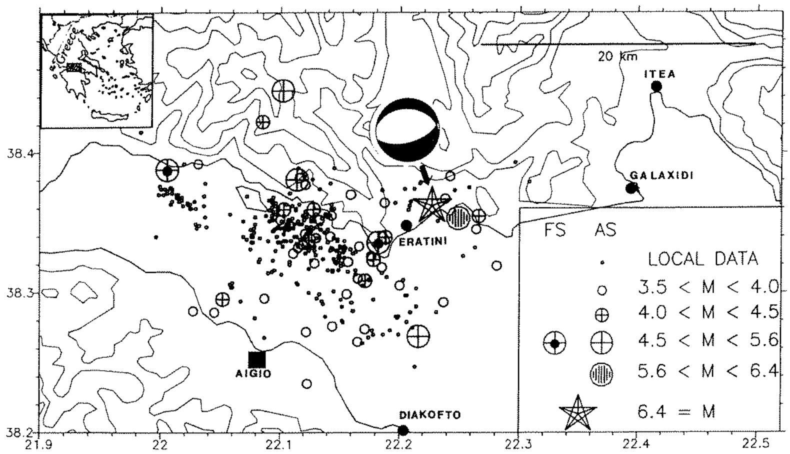


Fig. 1. Map of epicentres of the Aigio seismic (the star denotes the $M_w = 6.4$ mainshock). Square shows the location of the analong accelerograph (SMA-1) that recorded the mainshock and aftershocks in the town of Aigio (OTE-building). The focal mechanism of the mainshock is also given [Karakostas *et al.*, 1997].

mainshock and subsequent seismic activity in Aigio (National Telecommunications Organization — OTE building) are also given in Fig. 1.

The earthquake of 15 June was not the only known strong earthquake to strike Aigio and its surrounding areas. In fact, a number of similar or even stronger events have, according to documents, occurred in this area and its vicinity since historical times, often causing massive destruction in Aigio and in other major towns and localities. Table 2 lists all known destructive earthquakes in the area, including their (estimated) coordinates and magnitude. When necessary, two MMI intensities are given for each earthquake — the maximum observed (with the corresponding location) and the one in Aigio. A summary of reported effects (adapted from Papazachos and Papazachou [1997] and Ambraseys and Jackson [1990]) is also included.

This study presents and analyses the available strong motion data and summarises the effects of the Aigio earthquakes on typical (mainly residential) buildings. More specifically, an attempt is made to analyse the relative contribution of source and site effects to the observed features of strong ground motion, which are then compared to those of other Greek earthquakes with similar magnitudes and epicentral distances. Also, the attenuation of strong ground motion (peak acceleration and velocity) is evaluated and compared with the mean empirical curves for the Greek territory. The possible influence of structural response on the recording of the mainshock in the town of Aigio is also investigated. Damage to typical buildings (masonry and reinforced concrete) is described extensively, and damage distribution within the town of Aigio is discussed in connection to site effects. Finally, structural behaviour is examined in relation to the seismic code in force, and the contribution of the revised (1984) code provisions in increasing the

Table 2. Historical to present-day shallow earthquakes (estimated epicentres and magnitudes are given) that have seriously affected the town of Aigio. When necessary, two MMI intensities are given for an earthquake: the maximum observed and the one in Aigio.

Date	Lat. Long.	M	I	Location	Remarks
373 BC, winter	38.2 22.2	6.8	X	Eliki-Aigio	Very big tsunami; Helike and Bura destroyed; many killed/drowned
23 AD	38.3 22.1	6.3	VIII	Aigio	Aigio heavily damaged
61 AD	38.2 22.2	6.3	VIII	Achaia	Cities in Achaia and Macedonia severely damaged
6/1402	38.1 22.4	7.0	IX VIII	Xylocastro Aigio	Xylocastro, Vostitsa (Aigio), Diakofto destroyed, several killed; big tsunami
1664	37.9 21.0	6.6	VIII V	Zante Aigio	Zante: houses, town walls destroyed; Aigio, Patras violently shaken
14/05/1748	38.2 22.2	6.6	IX	Aigio	Foreshocks, big tsunami; Aigio severely damaged
23/8/1817	38.3 21.1	6.6	IX	Aigio	big tsunami; Aigio severely damaged, 65 killed
26/12/1861	38.25 22.16	6.7	X VIII	Valimitika Aigio	Valimitika levelled, Egio damaged; 20 killed (14 in Aigio/province); big tsunami
01/09/1870	38.48 22.55	6.8	IX VII	Arachova Aigio	Strong foreshock, many aftershocks; > 2000 buildings destroyed; 117 killed, 380 injured
09/09/1888	38.23 22.11	6.3	IX VIII	Valimitika Aigio	Strong aftershocks; villages destroyed; several collapses in Aigio (one killed)
30/05/1909	38.44 22.14	6.2	VIII VII	Dafnochori Aigio	Serious destruction in Dafnochori
20/01/1914	38.35 22.07	5.1	V	Aigio	
27/01/1915	38.36 20.60	6.6	IX V	Exoghe Aigio	Many collapses in Exoghe, Kolieri villages (Ithake); violently felt in Aigio
24/12/1917	38.40 21.70	6.0	VIII VI	Naupaktos Aigio	Severely felt in Aigio
15/11/1959	37.78 20.53	6.8	VII V	Zante Aigio	Foreshock; some damage in Zante
06/07/1965	38.27 22.30	6.3	VIII$^+$ VII	Eratine Aigio	575 houses destroyed in Achaia, Phokida; one killed, six injured

Table 2. (*Continued*)

Date	Lat. Long.	M	I	Location	Remarks
04/01/1967	38.25 22.07	5.5	V	Aigio	
24/02/1981	38.07 23.00	6.7	IX V+	Perachora Aigio	Destruction in Corinthia, Boetia, Attica, Phokida and Euboea; 22 544 buildings destroyed; 20 killed, 500 injured
18/11/1992	38.34 22.44	5.7	V	Aigio	
14/07/1993	38.17 21.77	5.5	V	Aigio	
15/06/1995	38.36 22.22	6.4	VIII	Aigio	Four buildings collapsed, 1071 severely amaged; 26 killed

seismic safety of structures, as well as the importance of strength reserves of existing buildings in alleviating the consequences of strong ground motions are discussed.

2. Strong Motion Data

2.1. *Strong motion recordings and spectra*

The mainshock and largest aftershock were recorded by ten three-component analog accelerographs (SMA-1) of the permanent National Strong Motion Network. Six of the instruments belong to GI-NOA and are located in the towns of Aigio, Amfissa, Nafpaktos and Livadia (on the ground floor or in the basement of two- to three-storey buildings), the city of Patras and at Mornos dam. Four instruments belong to the Institute of Engineering Seismology and Earthquake Engineering (ITSAK) and are located in the city of Patras (in the basement of the building of the National Bank of Greece and on the ground floor of two churches) and in the town of Corinthos (in the basement of the Town Hall). On the day following the earthquake, ITSAK installed another four digital accelerographs (SSA-2), two in Aigio, of which one in the basement of the National Telecommunications Organization - OTE building, beneath GI-NOA's instrument — located on the ground floor (see Fig. 13) — and another on the ground floor of the Aigio hospital; one in Diakofto village, east of Aigio; and one in Eratini village, north of Aigio, across the gulf, and very close to the estimated mainshock epicentre. These instruments recorded over 100 accelerograms in about one month of operation.

The extensive damage in downtown Aigio indicates that this area experienced the strongest shaking during the $M_w = 6.4$ mainshock. As already mentioned, the only accelerograph in operation at the time of the mainshock was located on

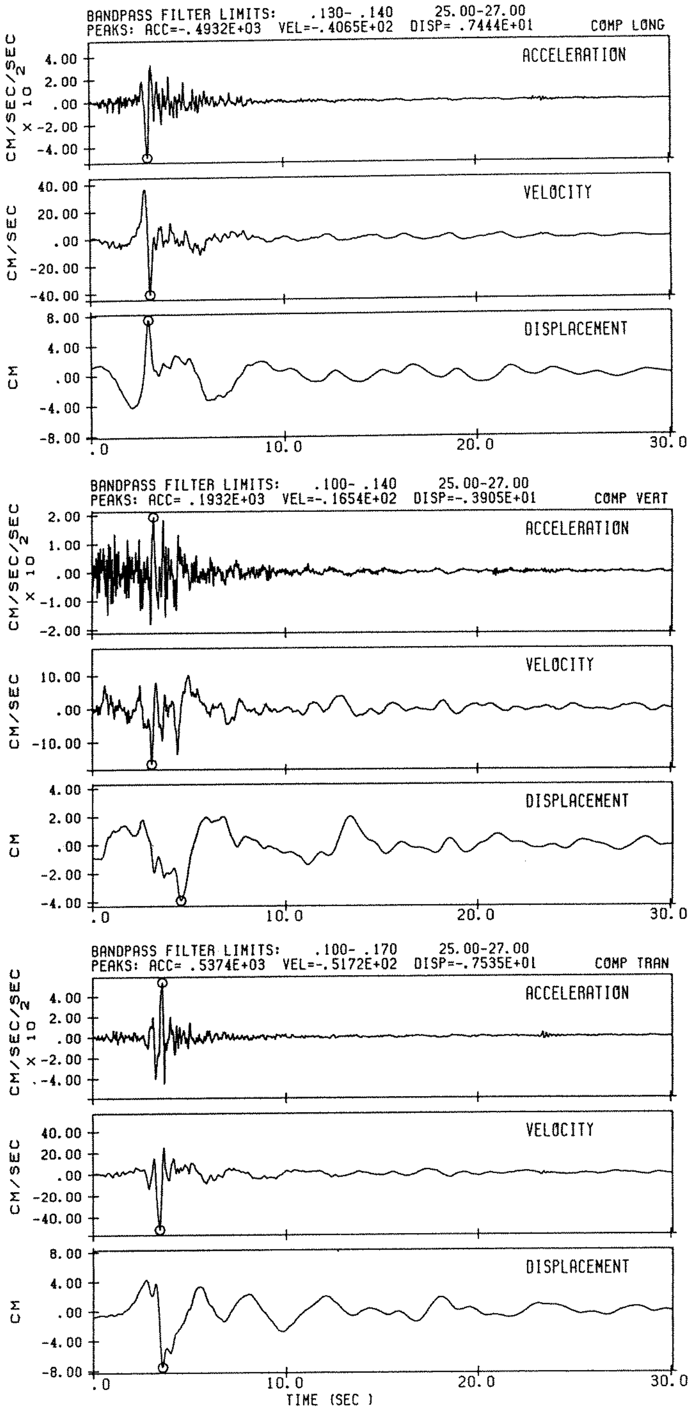
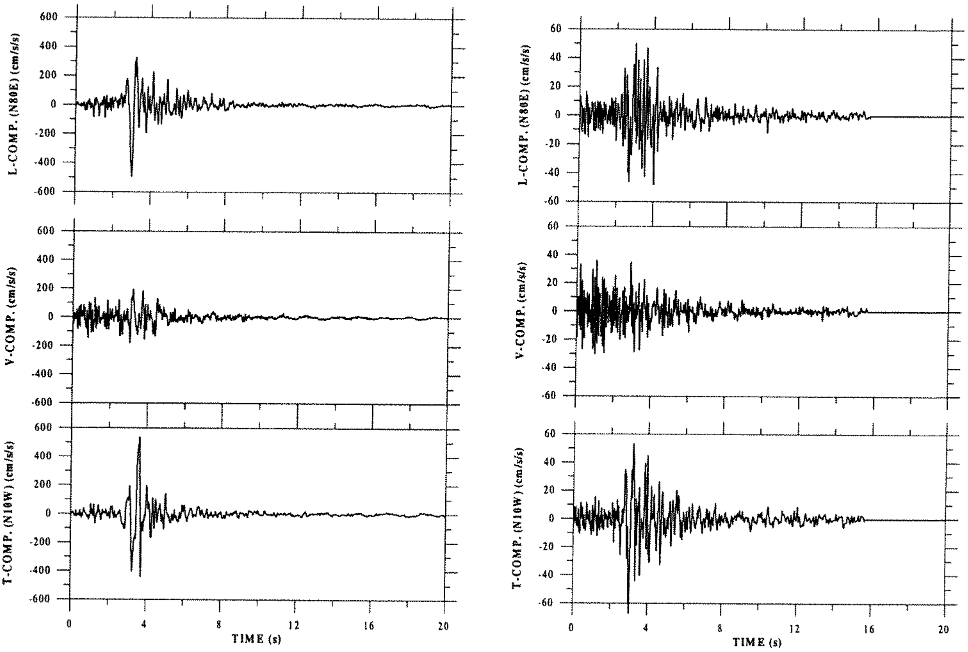


Fig. 2. Corrected time histories of acceleration, velocity and displacement of the mainshock recorded at the OTE building in Aigio.

the ground floor of a two-storey reinforced concrete building with an underground basement (OTE building), about 150 m far from the collapsed building on Despotopoulou Street in Aigio. A detailed description of the OTE building and a discussion of possible structural-response effects on the recordings obtained are given below.

The time histories of acceleration, velocity and displacement for the Aigio mainshock are plotted in Fig. 2 [Kalogeras and Stavrakakis, 1998]. Both horizontal components display very high peak values of acceleration, namely 0.50 g and 0.54 g in the longitudinal (N80°E) and transverse (N10°W) direction, respectively. In the vertical direction, a peak ground acceleration of 0.20 g was recorded. The highest values of ground velocity and displacement were observed in the transverse component at 52 cm/sec and 7.5 cm respectively. The mainshock accelerograms are shown again in Fig. 3 in comparison with the accelerograms of the largest aftershock, which occurred about 15 minutes later. Figure 4 displays the corresponding Fourier amplitude spectra of the horizontal components of both events. As can be clearly seen in this figure, the mainshock in particular and, to a lesser degree, the largest aftershock, released energy predominantly into the frequency band between 1.5–2.5 Hz. Another striking feature of the mainshock is the domination of large-amplitude pulses — relatively simple, one-period pulses of about 0.5 sec dura-



(a) (b)

Fig. 3. Acceleration traces of the Aigio (a) mainshock and (b) largest aftershock as recorded by the accelerograph at the OTE-building (ground floor) in downtown Aigio.

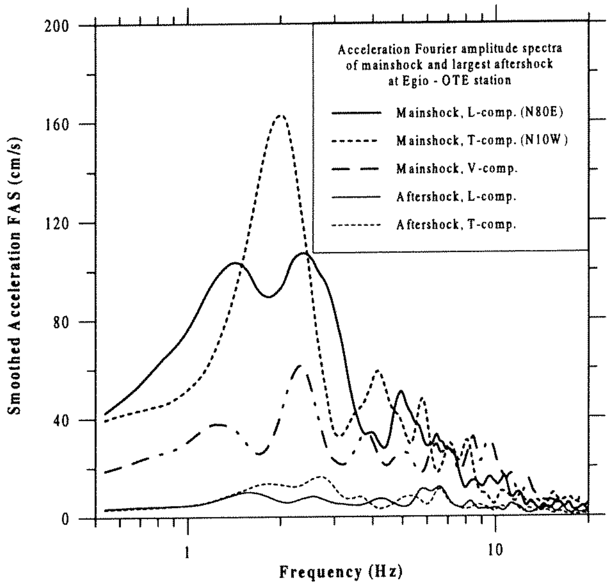


Fig. 4. Fourier amplitude spectra (horizontal components of acceleration) of Aigio mainshock ($M_w = 6.4$) and largest aftershock ($M_w = 5.6$) at Aigio's OTE station. For the former event, the spectrum of the vertical component is also shown.

tion. Also noteworthy is the remarkably high peak value of the horizontal velocity, 52 cm/s. The duration of the strong motion, with acceleration above 0.05 g, is about 6 sec. The vertical peak ground acceleration, although quite high, gives a peak vertical to peak horizontal acceleration ratio of about 0.4, considerably lower than the value of 0.7 adopted by the New Greek Seismic Code of 1995 (NEAK). Some of the above observations are also apparent in the tripartite logarithmic response spectra of the mainshock, calculated for five damping values (Fig. 5). The effective peak acceleration calculated according to FEMA (1985) is 0.43 g, much higher than the value of 0.24 g proposed by NEAK for seismic zone III, to which the town of Aigio belongs. It should nevertheless be mentioned that in spite of the large recorded peak accelerations and subsequently large computed effective accelerations, the damage was not as severe as one might have expected. The ratio of the peak ground velocity to the peak ground acceleration for the largest horizontal component (T-direction) is 96 cm/s/g, a value indicative of a small hypocentral distance and local site conditions that can be described as cohesive deposits [Seed *et al.*, 1976]. Usually, large ground velocities result from ground motions of velocity-pulse type, which occur in the near field of strong shallow earthquakes and whose features are mainly determined by the characteristics of the seismic source (source mechanism, directivity effects, etc.). Recent examples of ground motion exhibiting the above features were provided by the 1992 Erzican-Turkey earthquake [Erzican, Turkey Earthquake Reconnaissance Report, 1993] and by the 1994 Northridge, California, earthquake [Northridge Earthquake Reconnaissance Report, 1995].

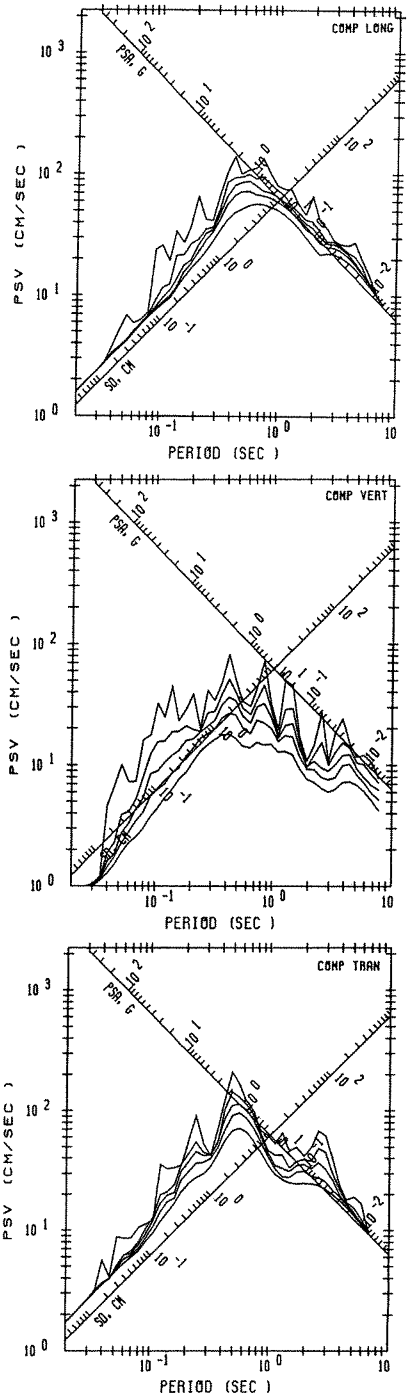


Fig. 5. Tripartite logarithmic response spectra of the mainshock recording at OTE station in Aigio, for five damping values (D = 0%, 2%, 5%, 10% and 20%).

Table 3. Seismological and strong ground-motion information on recent destructive normal-faulting earthquakes in Greece (adapted from Papazachos and Papazachou [1997]).

Location	Date	M_w	R (km)	a_g (g)	v_g (cm/s)	d_g (cm)	v_g/a_g (cm/s/g)	BD* (s)	EPA** (g)	SCZ*** Zone-g
Thessaloniki	20/6/78	6.4	29	0.15	16.7	3.4	111	6	0.13	II - 0.16
Corinthos	24/2/81	6.6	30	0.29	24.6	6.7	85	11	0.24	III - 0.24
Kalamata	13/9/86	5.9	12	0.27	32.3	7.2	120	4	0.27	III - 0.24
Kozani	13/5/95	6.5	19	0.21	8.8	1.5	42	7	0.14	I - 0.12
Aigio	15/6/95	6.4	18	0.54	51.7	7.5	96	6	0.43	III - 0.24

*Bracketed duration, time span between the first and last peak with $a_g \geq 0.05$ g.
**Effective Peak Acceleration according to FEMA (1985).
***Seismic Code Zone — Proposed effective horizontal acceleration (NEAK).

Table 3 summarises seismological data and strong ground motion characteristics of the five largest normal-faulting earthquakes that occurred in Greece during the last two decades and damaged modern constructions. The acceleration response spectra of the strongest horizontal components of these events are shown in Fig. 6.

Apart from the Kalamata earthquake ($M_w \approx 6.0$), all other events in Table 3 have comparable magnitudes ($M_w \approx 6.5$). The strong ground motion of the Kalamata event was recorded at a smaller epicentral distance and had a shorter bracketed duration. For all of the events, the effective peak ground accelerations (EPA) are equal to, or smaller than, the observed peak ground accelerations. As

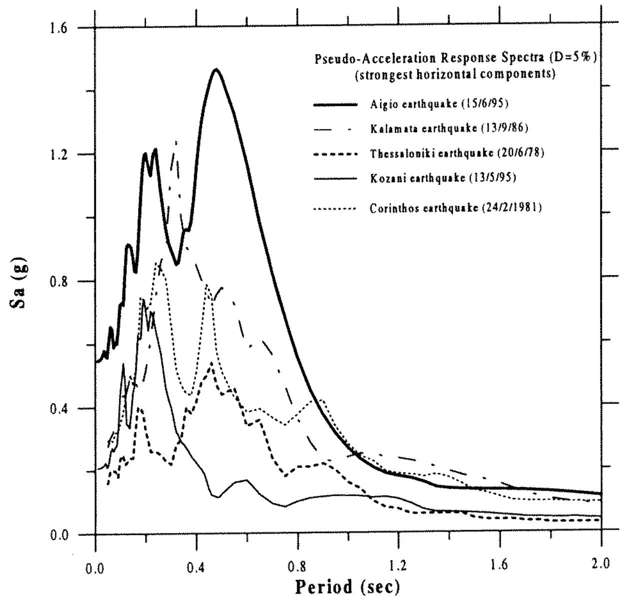


Fig. 6. Acceleration response spectra of the five disastrous normal faulting earthquakes in Greece.

can be seen from Table 3, the zone-dependent effective horizontal accelerations proposed by NEAK are in all cases comparable to EPA, with the exception of Aigio. The severity of the Aigio ground shaking, in the area where it was recorded, is also clearly seen by comparing the acceleration response spectra for all the events of Table 3 (Fig. 6): in almost the entire range of periods of engineering importance (0.2–1.0 sec) the highest spectral values are observed in the Aigio earthquake.

Figure 7 displays the T-component (N10°W) versus L-component (N80°E) displacement diagram of the pulse part of the OTE building recording of the mainshock. The displacement diagram shows that the N10°W and the N80°E motions are comparable and clearly separated in time, the latter preceding the former.

Figure 8 shows the average Fourier amplitude spectra of the two horizontal components of acceleration recorded at seven locations with different azimuths and distances from the epicentre of the Aigio earthquake. In all spectra there is a "bump" in the frequency range of 1.5–2.5 Hz (period range of 0.40–0.65 sec), suggesting that the source radiated elastic energy chiefly into that band. Directivity effects can also be inferred from this figure. Thus, the striking difference of the Aigio spectrum from the Mornos and Amfissa spectra, recorded at about the same epicentral distances, cannot be attributed to site and topographic effects alone, although there are some indications that these effects were also significant in Aigio (see below). Yet, the number of recordings is insufficient to permit definite conclusions, and further theoretical modelling is necessary to better understand the energy radiation pattern and the resultant strong motion wave field.

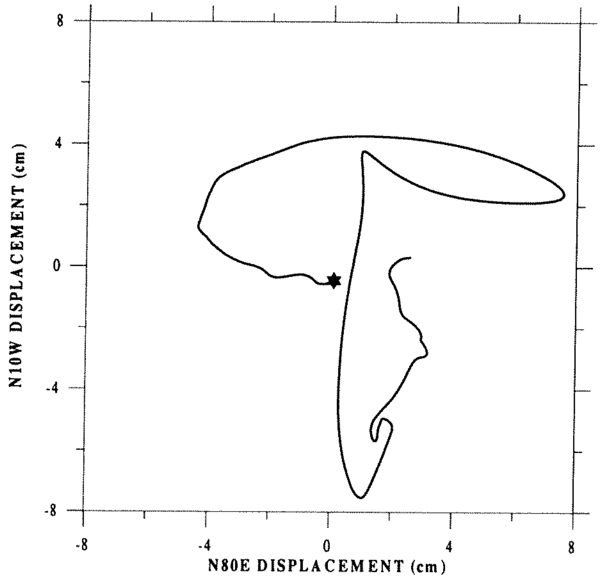


Fig. 7. Aigio mainshock: N10°W versus N80°E displacement, strongest-pulse part (1–5.5 sec) of the Aigio's OTE-station recording. Star indicates beginning of pulse part.

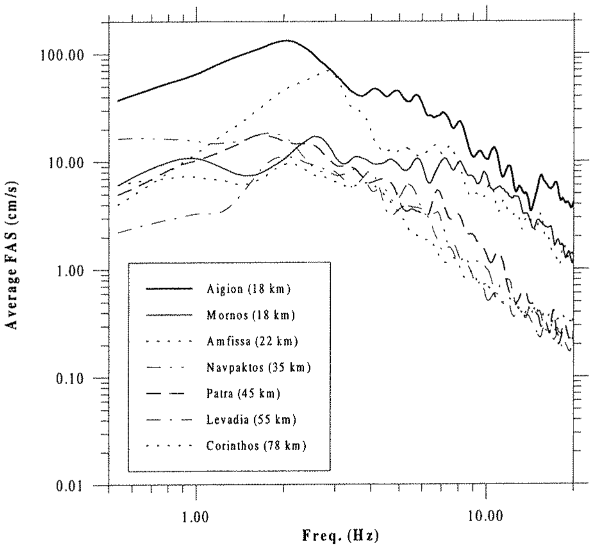


Fig. 8. Aigio mainshock: average Fourier amplitude spectra of the two horizontal components of acceleration at seven locations (permanent accelerographic stations) at different azimuths and distances (in brackets) from the epicentre. Note the "bump" in the frequency band 1 Hz–3 Hz present in all spectra.

2.2. *Strong motion attenuation*

Papazachos and Papazachou [1997] carried out a comprehensive study of macroseismic-intensity data in Greece, from historical to present times. Subsequent macroseismic-attenuation studies, performed on this large data set, showed two models to be particularly successful: the model of anisotropic (elliptic) radiation of seismic waves [Papazachos, 1992] and the azimuthal-attenuation model [Margaris, 1994]. These models were applied to estimate the seismic hazard in Greece [Margaris and Papazachos, 1994]. The two models were used to compute the synthetic isoseismal curves of the Aigio earthquake, shown in Fig. 9 along with macroseismic data (on the Modified Mercalli scale), compiled by Papazachos *et al.* [1997] from various sources. The orientation of the principal axis of the elliptic-attenuation model, which is also the principal axis of azimuthal attenuation, is found to be N86°E. This orientation is compatible with the average orientation of all available isoseismals in the seismogenic zone 8b, to which the Aigio event belongs, estimated to be N82°E ± 40° [Margaris, 1994].

To study the attenuation of the Aigio-earthquake strong ground motion, all available accelerograms were used. These came from ten stations belonging to the permanent strong motion network operated by GI-NOA and ITSAK, covering a wide range of azimuths, epicentral distances and site conditions. The peak values of horizontal acceleration and velocity at the ten sites, i.e. a total of 20 components-values, versus epicentral distance from the Aigio mainshock are

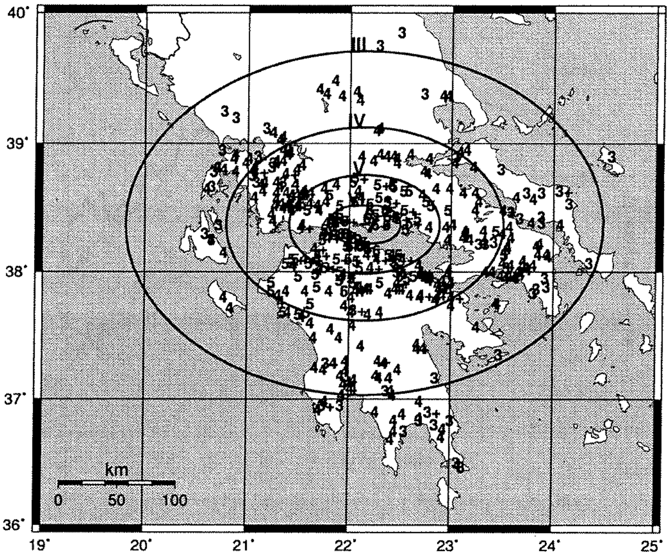
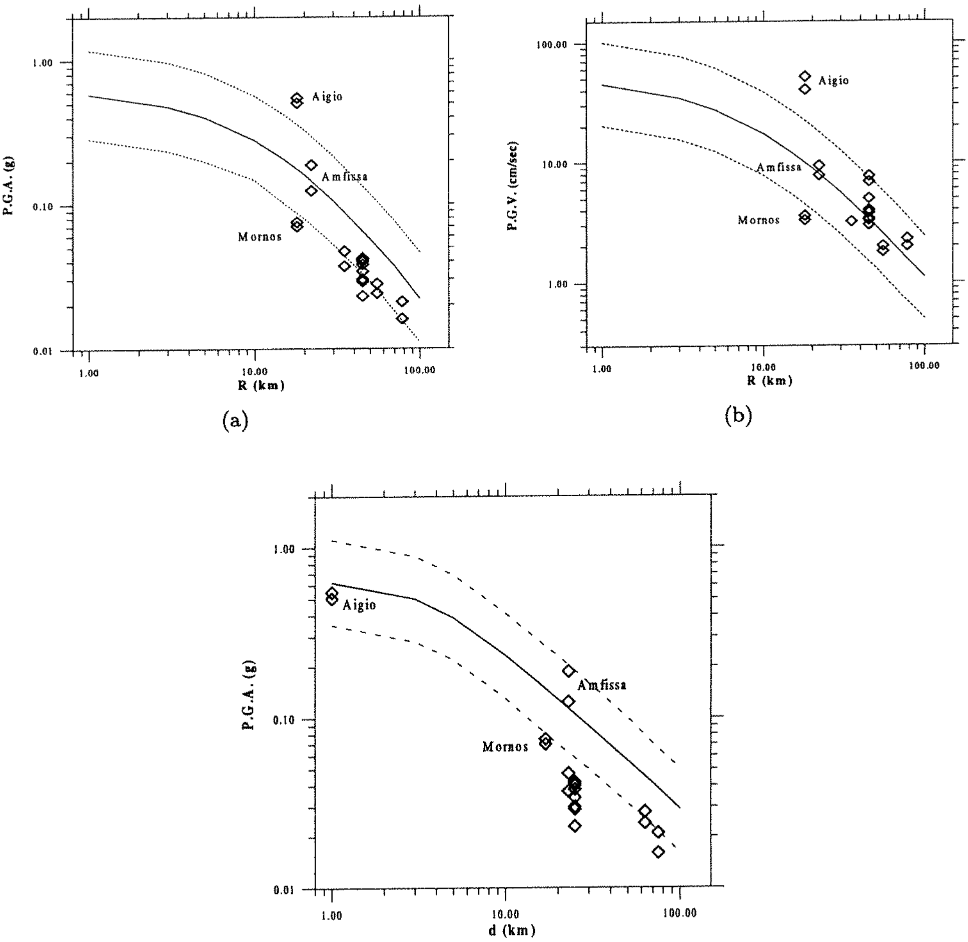


Fig. 9. Modified-Mercalli (MM) intensities reported for the Aigio earthquake and isoseismal curves derived on the basis of the model proposed by Papazachos [1992]; the model incorporates the effect of anisotropic (elliptic) radiation from the source as well as geometric spreading and inelastic attenuation effects. (Figure reproduced from Papazachos *et al.* [1997].)

presented in Figs. 10(a) and 10(b). Also shown are the expected mean and ± one standard deviation attenuation curves proposed for the Greek territory for a $M_w = 6.4$ event and intermediate soil conditions [Theodulidis and Papazachos, 1992]. It is remarkable that only the Aigio data (epicentral distance R = 18 km) significantly exceed the mean plus one standard deviation values, both in acceleration and velocity. By comparison, the peak values recorded at the Mornos dam site, at roughly the same epicentral distance with the Aigio site but different azimuth, are well below the mean values. The Amfissa-site data, on the other hand, again coming from a similar epicentral distance (R = 22 km) but different azimuth as compared to both Aigio and Mornos locations, are perfectly approximated by the mean curve. At larger distances, nonetheless, the predicted mean values are generally in good agreement with the observed acceleration and velocity data. These comparisons clearly show how dangerous it may be to rely on averaged data in making predictions concerning the properties of strong ground motion, especially in the near field of strong earthquakes. In fact, empirical predictive models for the area of Greece suffer from lack of data in the near field ($R < 20$ km) of relatively strong ($M_w > 6.0$) earthquakes [Theodulidis and Papazachos, 1992]. But even a larger and more complete dataset cannot warrant that a "general" predictive model can be developed that will be able to account for the rich variety of source characteristics. Thus, for example, the empirical predictive model for peak ground acceleration, based on data including large earthquakes ($M > 6.0$) in Europe and adjacent area recorded in the near field (shortest distance station-to-surface projection of the



(a)

(b)

(c)

Fig. 10. Aigio mainshock: attenuation of strong ground motion. Data from ten accelerographic stations of the permanent national network. (a) Peak horizontal accelerations and (b) velocities and the mean expected curves for Greece (±1 s.d.) calculated for a $M_w = 6.4$ earthquake and intermediate soil conditions [Theodulidis and Papazachos, 1992]. (c) Peak horizontal accelerations and the mean expected curves for Europe (± 1 s.d.) calculated for a $M_s = 6.4$ earthquake [Ambraseys *et al.*, 1996]. R is the epicentral and d is the shortest distance from the station to the surface projection of the rupture area, as presented in Bernard *et al.* (1997) (Figs. 4 and 5).

rupture area, $d \leq 20$ km) [Ambraseys *et al.*, 1996], predicts well the values recorded in Aigio but it is less efficient in approximating values recorded at larger distances [Fig. 10(c)].

2.3. *Site effects*

After the earthquake, geotechnical boreholes were drilled on four critical locations within the town of Aigio, including the sites of the OTE and the collapsed building on Despotopoulou Street [Tsiabaos and Sabatakakis, 1996]. Two downhole and one cross-hole measurements were performed. In addition, data from previous geotechnical studies, including another 20 boreholes, were gathered and revised. On the basis of this considerable amount of information, four major soil types were found to characterise the subsurface structure in Aigio [Tsiabaos and Sabatakakis, 1996].

(I) Shoreside soft deposits: mostly brownish ashes — dark ashes, soft clays (CL & CH) with organic material, soft silts (ML), and silty sands (SM, SW-SM); locally clayey-silty sands (SC, SM-SC) and silty sandy gravel (GM, GP). This type is found exclusively in the northern shoreside area and has a thickness of 10–12 m at the harbour's coast.

(II) Recent deposits: sandy clays (CL) and clayey sands (SC) with silty sandy gravel (GW-GM). N_{SPT} from 8–15 to > 50 (sandy gravel), V_S from 150–200 m/s. This type is the surface layer in the central, eastern and south-eastern parts of the town and has a thickness of up to 3 m.

(III) Quaternary deposits of mixed phase, with two subtypes: (IIIa) dense-very dense deposits of sandy gravel with shingles (GC, GM) and silty-sand inlays (SM, SM-SC, SP-SC), $V_S \sim 450$–500 m/s; (IIIb) brownish dark brownish-brown-reddish compact-very compact sandy clays (CL) interchanging with densely-very densely deposited sandy silts (SM, SM-SC, ML), $V_S \sim 300$–350 m/s. Type III soil is found on the surface in the south-western part of the town and underlies type II in the central, eastern and south-eastern parts, with a thickness of 17–25 m. Subtype IIIa overlies subtype IIIb and has a thickness of 8–10 m in the south-western part of the town, almost vanishing in the central and south-eastern parts.

(IV) Conglomerates: mixed, loose to well-bound with brownish-coloured sandstone marl. This material ($V_S > 700$ m/s) is considered "bedrock" in site-response studies.

The above geotechnical information was used in site-response studies in the town Aigio and its surroundings. An important conclusion is that the strong motion characteristics observed in the OTE building recording largely reflect source characteristics (rupture process) rather than site effects. Thus, whereas the strongest, pulse part of the recording has a period of 0.45 sec, the primary resonance of the soil structure under the OTE building occurs at 0.25–0.30 sec [Gazetas *et al.*, 1995]. Thus, the "bedrock" time histories, obtained by deconvolving the OTE building recording, retained their basic characteristics. Another important result is that there is generally a good agreement between the observed damage distribution and the computed site-dependent spectral accelerations for the periods corresponding to the fundamental resonances of typical residential buildings in Aigio (0.2–0.4 sec), whereas topography is estimated to have affected (increased or decreased) the relevant spectral accelerations by no more than 50% [Boukouvalas, 1996].

3. Effects of the Earthquake

3.1. *Building types, ductility demands and seismic code provisions*

The majority of buildings in Aigio can be grouped into three broad classes according to their load bearing system. These classes and their basic characteristics are listed in Table 4. Buildings in class A are generally one- or two-storey old houses, many of them over 50 years old, with load-bearing masonry walls made of stone or brick, weak mortar, and usually, but not always, without any seismic provisions such as horizontal concrete or wooden tie-belts. Interior partitions are usually made either of low-quality brick or "bagdati", which is an old type of wall construction consisting of horizontal wooden planks, 3–4 cm wide, placed in two parallel vertical planes at distances of about 1–2 cm apart and covered by lime mortar mixed with straw. Floors and roofs are typically wooden, although in more recent constructions reinforced concrete slabs have also been used, providing a diaphragm that ties together all the load-bearing walls [Anagnostopoulos *et al.*, 1987; Lekidis and Manos, 1993].

Buildings in class B are made of reinforced concrete and constitute the majority of residential and office buildings in Greek cities and towns. Then number of storeys varies typically from one to seven, depending upon the area and the height limitations applicable at the time of their construction. These buildings are made of cast-in-place reinforced concrete, with unreinforced hollow brick walls used as partitions. Their load-bearing system, both for vertical and horizontal loads, is a

Table 4. Types of typical buildings in Aigio.

Class	Description	Remarks
A	One- or two-storey buildings with masonry bearing walls.	Mostly old residential buildings or shops. Walls are made of stones or hollow bricks with mortar based on lime and more rarely on cement or mud. Typically without any seismic provisions, except for a small percentage that may have wooden or concrete tie-belts.
B	Modern reinforced concrete buildings between one to seven stories high.	Mostly residential or office buildings made of cast in place reinforced concrete. Unreinforced, hollow brick walls used as infills. Most of them designed in accordance with the Greek seismic provisions of 1959.
C	Special reinforced concrete buildings.	Usually buildings with large plan dimensions used for commercial or industrial operations, schools etc. Some with steel roofs. Most of them designed in accordance with the 1959 code.

skeleton of columns and beams on which the floor slabs are monolithically supported. In most cases, this system would not qualify as a ductile moment resisting frame but rather as an irregular space frame, whose layout has been formed primarily by architectural considerations. A few of these buildings have shear walls which, however, would not qualify as such under, e.g. current UBC or EC-8 standards. The foundation is usually on spread footings with interconnecting grade beams. In this category of buildings, an important characteristic that plays a key role in their response to earthquakes is the type of the ground storey. Sometime in the 1970s, the General Greek Building Code (not the code for the seismic design) permitted buildings to have an open ground storey, called "pilotis", for car parks, flowerbeds, playgrounds etc., without counting it in the maximum permitted total floor area. This became very popular, but created a "soft" first storey, due to the drastic reduction of brick infills in comparison to the storeys above. A similar, but not as severe, problem is created with ground storeys used as shops, due to the elimination of several infill walls for creating large front windows and large continuous interior spaces.

The third category of buildings, C in Table 4, includes reinforced concrete structures with relatively large plan dimensions used for industrial or commercial operations, schools, etc. The load-bearing system of such buildings, typically one to two storeys high, consists usually of well-defined moment resisting frames, though not with ductility levels proposed by modern seismic codes. The number of buildings in this class is a small fraction of that of the buildings in categories A and B.

The great majority of buildings in categories B and C have been designed in accordance with the Greek Seismic Code of 1959, which was revised in 1984 and replaced by the New Greek Seismic Code (NEAK) in 1995.

For Aigio the base shear coefficient, according to the 1959 Greek Seismic Code, was $\epsilon = 0.06$, 0.08 and 0.12 for firm, medium and soft soils, respectively. This coefficient was constant, independent of the building's period and applied uniformly to all buildings. Since the 1959 Code was based on the allowable-stress design method, the coefficient has been modified to account for a factor of safety of 1.75, a 20% increase in allowable stresses for seismic design and a multi-degree of freedom effect expressed by the factor 0.85 (estimated for a four- to six-storey building) [Anagnostopoulos, 1986; Pitilakis *et al.*, 1992]. Thus, using a mean safety factor of $1.75/(1.20^*0.85) = 1.72$, the respective coefficients for ultimate strength design are found to be $\epsilon' = 0.10$, 0.14 and 0.21. To get an idea of the ductility demands imposed on the buildings of Aigio by the earthquake, the spectral accelerations (S_a) are compared with the three base shear coefficients applicable in Aigio (Fig. 11). As it can be easily seen, the ductility demands of the earthquake were quite high, mainly in the period range of 0.2–0.5 sec, above what is estimated to be the available ductility of the town buildings. A comparison of the response spectra of the recorded motion with the elastic design spectrum (for intermediate soil conditions) of the 1995 New Greek Seismic Code — based on ultimate strength design — indicates that the code spectrum is quite lower in the short and intermediate period ranges ($T \approx 0.1$–0.85 sec) and much higher at longer periods. In this respect the Aigio recording has many similarities to the 1986 Kalamata record, also a near-field recording but from a smaller event. This earthquake, as it is also apparent from the response spectrum of the recorded motion (Fig. 11), affected both low and middle-rise buildings (two to five storeys high) in the broader area of Aigio. For taller buildings with six to seven storeys and $T \geq 0.5$ sec, spectral accelerations of the recorded motions fall very fast, so this particular event was certainly not so severe for them, especially if one considers the period elongation caused even by some limited inelastic action due to concrete microcracking and cracked infills.

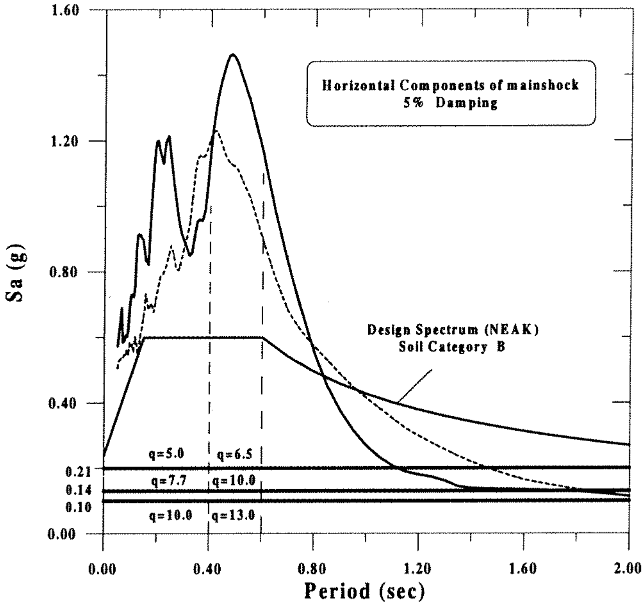


Fig. 11. Comparison of the response spectra of Aigio mainshock with the elastic design spectrum of the New Greek Seismic Code (soil category B) and the seismic coefficients of the 1959 (revised 1984) seismic provisions.

Moreover, it is noted that existing buildings possess a substantial amount of strength reserves (depending mainly on their redundancy and on the overstrength of individual structural members) as well as possible additional energy dissipation mechanisms, which contribute to a significant increase of their behaviour factor [Bertero, 1989]. Experience gathered from this and previous seismic events suggests that the seismic protection of Greek urban areas relies also on several alternative factors (such as infill walls, regular configuration of the structural system, proper material and workmanship quality, etc.) [FEMA, NEHRP, 1985; Arnold and Reitherman, 1981].

3.2. *Damage caused by the earthquake*

As mentioned previously, the main event produced the strongest motion ever recorded in Greece: it had peak ground accelerations of 0.54 g and 0.50 g in the horizontal directions. Judging from the distribution of damage, which was quite heavy in a certain area and light or non-existent in other town sections, it is clear that the ground motion varied considerably throughout the town. Such motion variation is to be expected from near-field events. The earthquake caused storey collapses and total failures of a significant number of buildings in Aigio and its broader vicinity, as well as certain failures of infrastructure facilities. Major damage to neither water and sewage systems nor to highway bridges was reported. In the port of Itea, a small town 35 km to the north-east of Aigio (Fig. 1), a significant settlement of concrete blocks and a rotation of the breakwater occurred. In many areas between Itea and Eratini, a village to the north of Aigio, as well as between Aigio and Diakofto, the coastline advanced several meters inland due to settlement. Diakofto is a seaside village 12 km east of Aigio. Liquefaction was observed in an area about 2 km west of the village of Diakofto, where several sand boils formed near the sealine, as well as in the basement of a house illegally built by the sea. In all cases the soil can be geotechnically characterised as sand clayey sand. The broader Aigio area belongs to the deformation zone caused by the 15 June 1995 earthquake.

Structural damage was concentrated mainly in the town of Aigio and in the villages of Valimitika, Rizomylos (between Aigio and Diakofto), Diakofto, Akrata (10 km east of Diakofto), Itea, Eratini, and other villages up to the borders of the adjacent Achaia Prefecture (district of Aigialia). Inspection committees from the Ministry of Public Works made a general classification for every damaged building in the broader area of Aigio and villages of the Aigialia area. This classification, described in detail below, refers to degree of damage ("red", "yellow", "green") and is independent of the building's category. Percentages of damage for the whole area of Aigio are 23%, 25% and 52% for red, yellow and green respectively [Karagiannis *et al.*, 1996]. In the town of Aigio damage was mainly concentrated in a strip along the direction approximately parallel to the coastline [Gazetas *et al.*, 1995]. The degree and density of damage distribution was remarkably lower in the southern part of the town, where the hospital (founded on rock) is located. Strong ground motion intensity also decreased much more rapidly towards the west of the town than to the east, a feature observed in the broader Aigio area as well.

Damage for different types of buildings is described in detail below.

(a) *Multi-storey concrete buildings*

There were four major collapses of multi-storey reinforced concrete buildings. One section of a six-storey apartment building on Despotopoulou Street, in which 17 people were killed and some were rescued from the ruins. This building, constructed in 1979, collapsed due to the mainshock. Inspection after the collapse revealed weak columns at the ground floor level, and the lack of a structural core and a well-defined structural frame for lateral loads. Also, drainage pipes were embedded in column sections, a practice not permitted by NEAK. One of the three wings of the seaside resort hotel "Eliki", a four-storey building with an appendage on top, also collapsed, resulting in the death of nine vacationers. This building, designed in 1969, was founded by the seaside on sand soil. The collapse of a three-storey office building with pilotis, belonging to an industrial complex of the Greek Army (EVO), was due to the existence of very strong beams and the lack of capacity design, since it was designed according to the 1959 Greek Seismic Code. Finally, a two-storey house with pilotis in the Aigio district of Myrtia also suffered total failure.

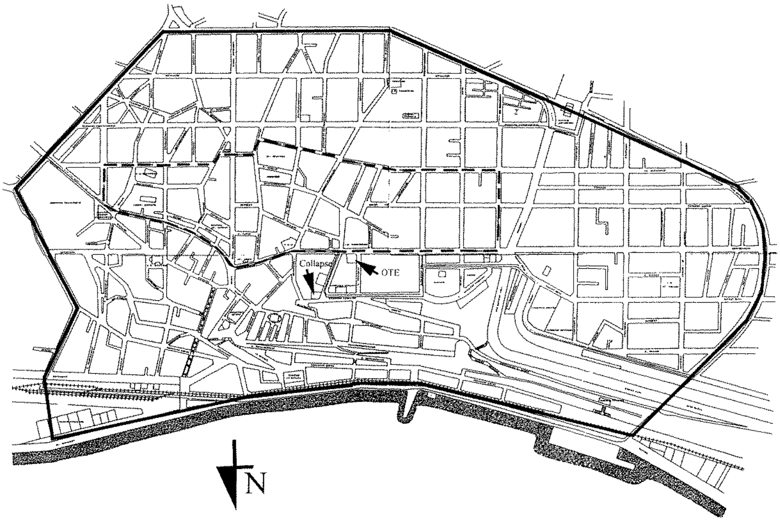


Fig. 12. Town plan of Aigio. Arrows indicate locations of OTE building and collapsed building on Despotopoulou Str.

A team of engineers from ITSAK investigated a zone of the central part of town almost parallel to the coastline. This zone is denoted by dashed lines in Fig. 12 and it is very near to the accelerograph which recorded the mainshock. Many multistorey concrete buildings belonging to this zone suffered complete column failures at ground floors and total shear-wall failures at ground and first floor levels. Because of these failures, formation of collapse mechanisms in the structural frames was imminent, and an emergency operation to support the weakened floors was promptly organised. This immediate response mitigated the destructive consequences of aftershocks, preventing additional collapses. It appears that in most cases no well-defined structural system for resisting lateral loads existed, while member and joint detailing was good for vertical loads only. Weaknesses known from previous events were once again observed as strong reminders of mistakes, omissions, oversights or even lack of knowledge during construction. These include insufficient longitudinal and transverse reinforcement, inadequate bar anchoring, sub-standard concrete quality, etc. A general remark applies to the behaviour of old RC buildings (of category B): these buildings, designed before the 1984 revised Seismic Code provisions for much smaller accelerations than what this event seems to have generated and with practically no ductility provisions, performed not nearly as bad as one might have expected. This should be attributed to the substantial resistance, strength and damping provided mainly by the infills — even those of poor quality — in combination with the short duration of the strong part of the earthquake motion.

The Laboratory of Reinforced Concrete at the University of Patras [Fardis, 1996] conducted a systematic investigation of damage to 1200 reinforced concrete and about 1000 masonry buildings in an area enclosed by the coastline to the north, the ring road to the west, Riga Ferraiou and Comninou Streets to the south, and Kanellopoulou Street to the east (denoted by thick solid lines in Fig. 12). In the investigation, percentages of damage refer to "green", "yellow" and "red" classification categories, according to the Damage and Usability State of buildings. A brief description of this classification follows:

"Green":

Original seismic capacity has not been decreased, the buildings are immediately usable and entry is unlimited.

"Yellow":

Buildings in this category have decreased seismic capacity and should be repaired. Usage is not permitted on a continuous basis.

"Red":

Buildings in this category are unsafe and entry is prohibited. Decision for demolition will be made on the basis of more thorough inspection.

Classification of the 1200 examined reinforced concrete buildings to red, yellow, and green categories is 2.5%, 20% and 77.5% respectively. Among the results of the investigation, an interesting one is the influence of the construction date on damage statistics. Buildings were divided in three categories according to age: new (10–15 years old, 25.5% of the total), middle age (15–35 years old, 65% of the total) and old (age $>$ 35 years, 9.5% of the total). The design of the new buildings followed the revised provisions of Greek Seismic Code (1984). The design of the middle age buildings was according to the 1959 Greek Seismic Code, while for the construction of the old ones no seismic provisions were followed. The previously mentioned, red-yellow-green classification yields for the new buildings a 1%-9%-90% distribution, for the middle-age ones 2%-23%-75% and for the old ones 9%-27%-64%. The damage statistics show that the contribution of the 1984 revised version of the Greek Seismic Code to the seismic resistance of buildings was significant [Fardis, 1996].

(b) *Masonry buildings*

Masonry buildings in the broader Aigio and Diakofto areas also suffered extensive damage. At the eastern entrance of the town of Aigio, in the vicinity of hotel "Eliki", several cases of stone masonry buildings with severe diagonal cracks and partially collapsed walls were observed. The buildings in category A paid the heaviest toll to the earthquake. Such buildings have low seismic resistance and practically no ductility. The vertical component of motion had also a detrimental effect by contributing to the disintegration of the walls. For the 1000 masonry buildings investigated by the Laboratory of Reinforced Concrete, University of Patras, the classification is 56%, 27% and 17% for "red", "yellow" and "green", respectively [Fardis, 1996].

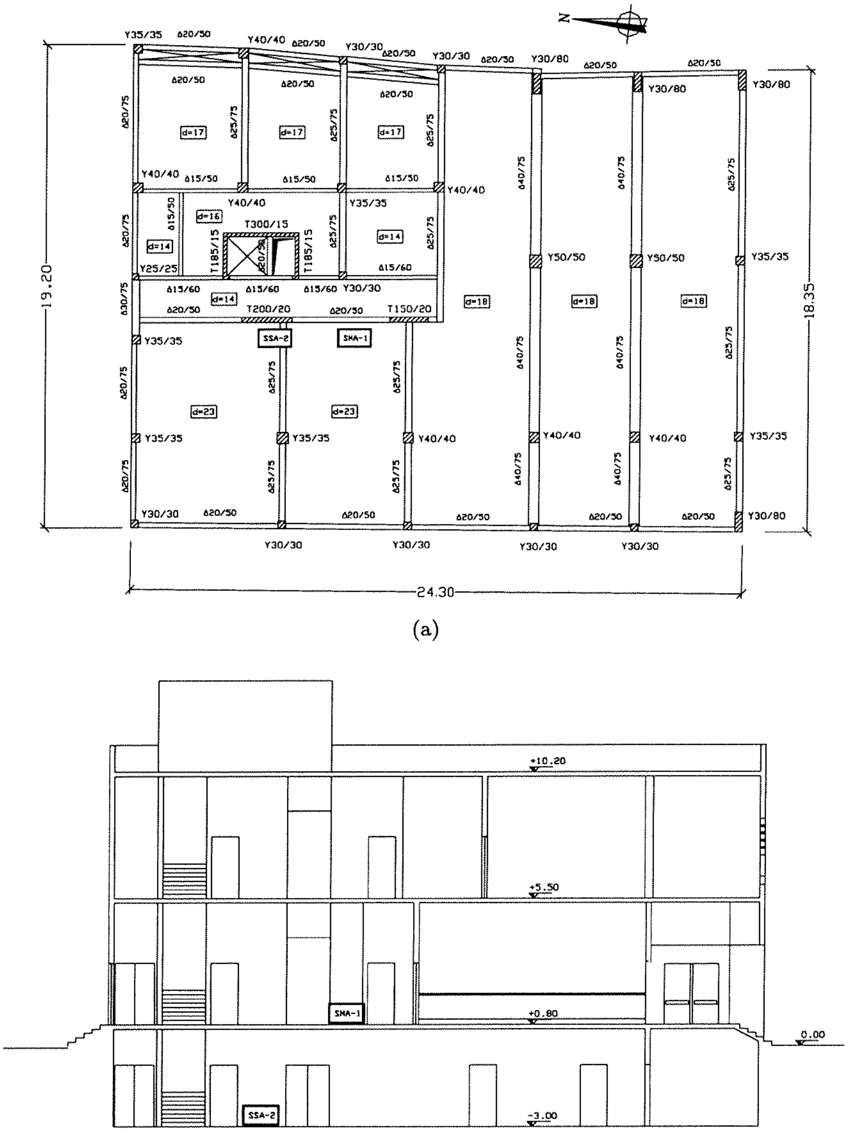
As mentioned earlier, damage from this strong event in Aigio was not as severe as one might have expected in view of the rather poor-quality seismic design and construction of most buildings, designed and built under the old code of 1959. This should be attributed to several factors, the most important of which are:

(1) The earthquake motion was most probably not as intense throughout the city as the record obtained at the OTE building would indicate. Large motion variations are typically observed at small epicentral distances (also the case here) and become even greater due to variations in local soil conditions. The fact that practically no damage was observed in a section (or sections) of town, where the quality of construction was statistically no different from that in the damaged areas, is a strong indication of this effect.
(2) The duration of the strong motion part of the earthquake was generally small (on the order of 6 sec) and insufficient to cause enough deterioration leading to subsequent widespread severe damage or failures.
(3) The substantial strength reserves possessed by buildings, due mainly to their redundancy, the infill walls and the overstrength of individual structural members.
(4) The increased energy dissipation provided by the cracking of the infill walls, even those of poor quality.

As the above factors have little to do with the seismic design coefficient, the Aigio earthquake provided once more evidence that it is such factors rather than the level of the code-specified seismic base shear coefficient that can save a building from collapse.

3.3. *Structural response of the telecommunications building in Aigio: A case study*

The only recording of the mainshock in the town of Aigio comes from the SMA-1 analog strong-motion accelerograph of the Geodynamic Institute of the National Observatory of Athens (GI-NOA), located on the ground floor of the National Telecommunications Organization (OTE) building. The framing plan of a typical floor, a longitudinal elevation section of the building as well as the position of the SMA-1 instrument are presented in Fig. 13. The use of concrete infill panels for architectural reasons, led to short captive columns on the facade of the building. The damage pattern of the building consisted only of shear failures of the short captive columns and cracks at the interior brick infill walls, which served as partitions.



(a)

(b)

Fig. 13. National Telecomunications Organization (OTE) building: (a) typical floor and (b) longitudinal elevation section. Positions of SMA-1 and SSA-2 accelerographs are also shown.

In the town of Aigio aftershocks were also recorded by a SSA-2 digital accelerograph installed by ITSAK in the basement of the building (beneath GI-NOA's instrument; see Fig. 13), as well as in the town hospital. A comparison, through mean Fourier spectra, of the recordings of the most significant recorded aftershock (on 19 June 1995, 06:19 GMT, see Table 1) in the basement and on the ground floor of the OTE building reveals no significant differences in their frequency content

(Fig. 14). An eigenvalue analysis of the building was performed using the ETABS Plus structural analysis program [Computers and Structures Inc., 1995] in accordance with the provisions of the 1995 New Greek Codes for Reinforced Concrete and Seismic Design, and gave the results presented in Table 5. Two cases were investigated, namely taking and not taking into account the existing, lightly reinforced, concrete infill panels at the perimeter of the building. It should be noted that no gaps were allowed between the infill panels and the adjacent elements of the load-bearing structural system. Thus, the existence of the infill panels greatly influenced the dynamic characteristics of the building. For the modelling process, the beam and panel elements of the ETABS Plus program were used. For beams and shear walls of the load-bearing system cracked stiffnesses were used (moment of inertia: 1/2 of the uncracked one for beams and 2/3 for shear walls, according to the Greek Codes used). For columns and infill panels uncracked stiffnesses were used, since for the latter a post-earthquake inspection revealed no cracking. The material quality corresponds to C12/15 for concrete and S400 for steel. In Fig. 15 the first two mode shapes of the model with infill panels of the OTE building are presented.

As can be seen from the Fourier amplitude spectrum of the mainshock (Fig. 4), the predominant period of the recording was about 0.45 sec, well apart from the fundamental period of the building. For the latter, eigenvalue analysis yielded a value of 0.17 sec at the beginning of the event, becoming about 0.19 sec if disintegration of the short captive columns is assumed. The difference between these values and the predominant period of the event is sufficiently high to prevent appearance

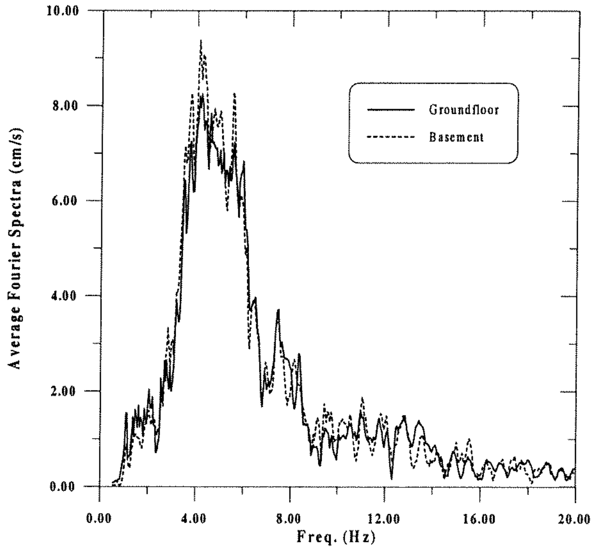
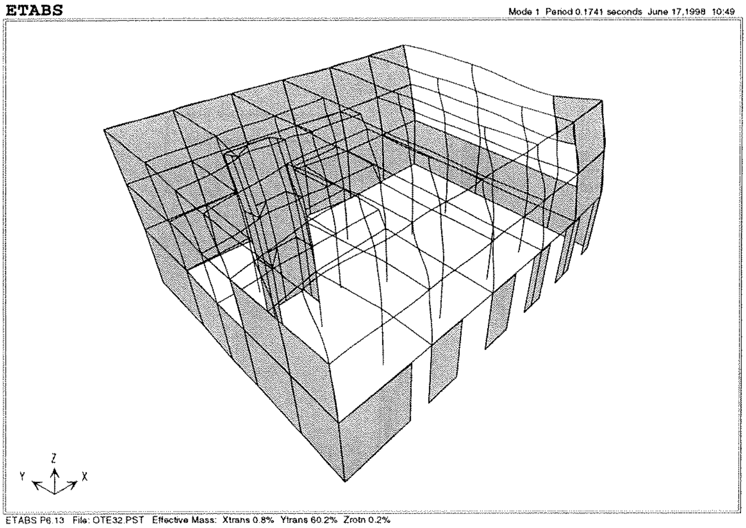


Fig. 14. Mean Fourier spectra of the horizontal components of the 19 June 1995 aftershock in the basement and on the ground floor of the OTE building.

Table 5. Results of eigenfrequency analysis of OTE building.

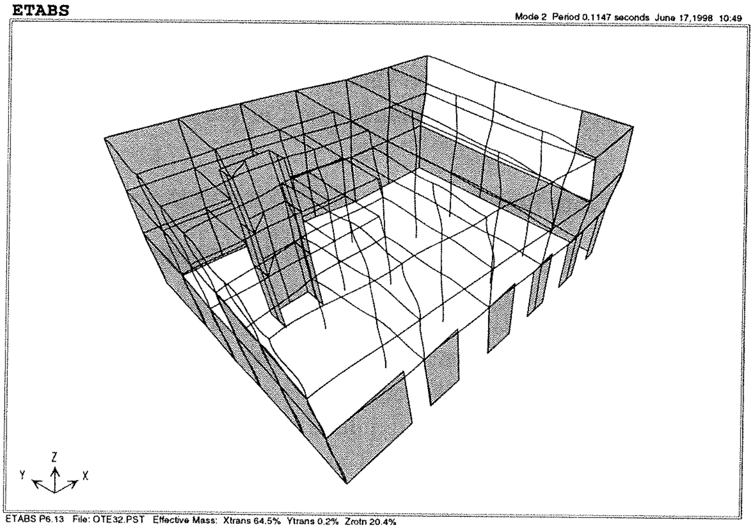
	Without infill panels				With infill panels			
Mode	Period (sec)	Effective mass factors (% mass)			Period (sec)	Effective mass factors (% mass)		
		X	Y	Z		X	Y	Z
1	0.31434	51.5	0.17	8.41	0.17414	0.80	60.18	0.19
2	0.26472	8.05	10.85	38.25	0.11474	64.48	0.15	20.37
3	0.23685	0.78	49.36	9.23	0.07665	28.12	3.43	38.28
4	0.08915	3.70	1.39	7.25	0.06565	1.50	21.82	17.74
5	0.07998	11.79	3.26	0.09	0.04146	2.15	0.27	12.93
6	0.07454	1.87	7.75	2.52	0.03485	0.00	13.97	10.2
7	0.04513	18.87	0.20	3.14	0.02720	2.69	0.18	5.29
8	0.03929	0.41	26.14	0.91	0.02280	0.01	0.00	3.44
9	0.02876	3.07	0.89	30.21	0.01720	0.24	0.00	0.75
Total		100.00	100.00	100.00		100.00	100.00	100.00

of resonance effects. Moreover, inspection revealed no evidence of soil-structure interaction effects, since no gaps between foundation and soil were observed. Thus, we are led to conclude that the OTE building response during the earthquake



(a)

Fig. 15. First two eigenmodes of the OTE model with infill panels.



(b)

Fig. 15. (*Continued*)

most probably did not affect the recording at the ground floor level. With the only reservation regarding possible non-linear and inelastic effects in structural response [Lekidis and Anagnostopoulos, 1992], the OTE recording can therefore be regarded as representing ground motion uncontaminated by structural and soil-structure interaction effects.

During the event, a very significant (almost 20-fold) increase of the shear forces at these columns, compared to storey-height length ones took place. Since the

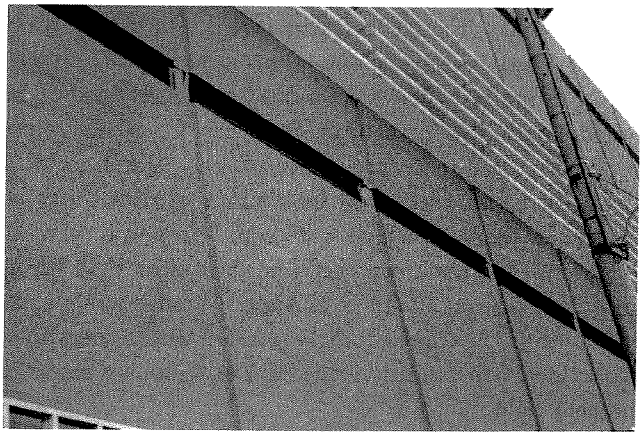


Fig. 16. National Telecommunications Organization (OTE) building. Failure of short columns.

columns were obviously not designed to withstand such forces, their shear failure was to be expected (Fig. 16). The lack of proper reinforcement of that captive columns led to total shear failure, even though the fundamental natural period of the building was far from the predominant period of the mainshock.

4. Discussion and Conclusions

The Aigio earthquake of 15 June 1995 ($M_w = 6.4$) produced the highest peak values of ground acceleration and velocity ever recorded in Greece. The horizontal components of the strong motion recording of the event in the town of Aigio, at an epicentral distance of 18 km, are dominated by large-amplitude pulses with peak accelerations of 0.54 g (N10°W component) and 0.50 g (N80°E component). These are relatively simple, one-period pulses, with a period of about 0.45 sec. Such pulses are characteristic of near-field motions from strong earthquakes with directivity effects [e.g. Northridge Earthquake Reconnaissance Report, 1995]. The displacement diagram of the strongest part of the Aigio recording shows a clear temporal separation into roughly N10°W and N80°E motions, the latter preceding the former.

The characteristic "bump" spike in the period range 0.4–0.65 sec is also clear in the horizontal components of the tripartite logarithmic spectra of the accelerograms. The Fourier spectra of the accelerograms of the main event, recorded at seven sites covering a wide range of epicentral distances and azimuths as well as soil conditions, all display the characteristic "bump" in the period band between 0.4 and 0.65 sec, suggesting that elastic energy was predominantly radiated into this band.

The mainshock peak horizontal accelerations and velocities recorded in the town of Aigio (OTE building) considerably exceed the range of values predicted by the mean attenuation curves of acceleration or velocity for the Greek territory, for a $M_w = 6.4$ event and intermediate soil conditions. On the other hand, at intermediate and larger distances, the observed data are in good agreement with the empirical predictive models (Figs. 10(a), and 10(b)). On the contrary, an empirical predictive model proposed for Europe and adjacent regions [Ambraseys *et al.*, 1996] predicts well the peak ground acceleration observed in Aigio, but has difficulty in predicting recorded values at intermediate distances. These discrepancies are a further indication of possible directivity or site effects. The macroseismic data and damage distribution provide additional indications of directivity effects. Judging from the distribution of damage, which was quite heavy in a certain area and light to almost non-existent in other town sections, it is clear that the ground motion varied considerably throughout the town of Aigio. Damage was mainly concentrated in a strip along the direction approximately parallel to the coastline. This could be attributed either to local soil condition variation or to source mechanism properties governing in the near field.

In Greece, there are seismic faults very close to urban areas. Even though some of these faults may at present be inactive, one cannot completely rule out the possibility of their generating destructive ground motion, as has been observed during recent small and moderate earthquakes [Anagnostopoulos *et al.*, 1989; Lekidis *et al.*, 1992; Lekidis and Manos, 1993; Theodulidis and Lekidis, 1996]. The event of June 1995 in the Aigio region also constitutes such an example. In spite of the very high recorded accelerations, the highest recorded in Greece, and the highest response spectra resulting from them, the overall damage was not as severe and widespread as one might have expected, despite the poor design and construction practices applied in the past. This could be attributed to a variety of factors:

(a) There was probably large variation of ground motion intensity throughout the town, since entire sections of the town suffered practically no damage, although there was no noticeable variation in the quality of the construction. Such motion variation is to be expected from near-field events.

(b) Old RC buildings designed before the 1984 revised Seismic Code for much smaller accelerations than what this event seems to have generated and with practically no ductility provisions, performed not nearly as badly as one might have expected. This should be attributed to the substantial resistance, strength and damping provided mainly by the infills, even those of poor quality, in combination with the short duration of the strong part of the earthquake motion. Had the latter been longer, the infills would disintegrate and their beneficial effects would seize to exist.

(c) RC buildings designed according to the revised (1984) code provisions possess substantial strength and ductility and their very satisfactory performance is a strong indication that the revised provisions, as far as design procedures and detailing recommendations are concerned, were quite adequate. This can serve also as an indication of the adequacy of the new code (put in force just after the Aigio earthquake), which constitutes a substantial improvement over the 1984 revision.

The OTE building response during the earthquake most probably did not affect the recording at the ground floor level. The OTE recording can therefore be regarded as representing ground motion uncontaminated by structural and soil-structure interaction effects. Strong shear forces were developed at the ground and first floor of the building, leading to failure of short captive columns on its perimeter. This earthquake has taught us, among other things, the need for eliminating short captive columns from design, as it is nearly impossible to make them avoid shear failures.

As a final conclusion, it should be emphasised that conservative seismic design coefficients alone cannot by themselves ensure the safety of structures, if they are not part of a comprehensive set of proper seismic design criteria and provisions. The 1995 Aigio and previous strong events have demonstrated the importance of several alternative factors towards a safe seismic behaviour of structures. Among such factors, some of which may not even enter the design process, one could mention the configuration of the structural system, good material and workmanship quality, sensible use of infill panels, etc. Due to these reasons, the overall performance of buildings properly designed and built in accordance with the 1984 and even 1959 seismic codes was quite satisfactory, even though the shaking at Aigio was among the strongest observed in Greece.

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