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A Modern Technique for the Retrieval and Processing of Historical Seismograms in Greece

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Abstract. A brief history of operation of the mechanical seismographs in Greece and the application of a technique for converting analog seismograms to digital traces in a form suitable for further processing or archiving are presented in this study. A short history about the installation of mechanical seismographs in Greece, the characteristics of these instruments, a reference on the usage of historical records, as well as a presentation of the procedure followed from the identification of the record to the archiving it as a digital file have been included.

Key words: historical seismograms, digitization, Greece.

1. Introduction

It is well known that Greece and the surrounding area is the most seismologically active area in Europe. At least one earthquake with magnitude $M \geqslant 6.5$ occurs in this area almost every year. This is the reason for which seismological instruments have started to operate in Athens since the end of the last century.

It is crucial for an active area to extend its seismological data base to the past and, moreover to combine the new digital data with the analog ones, or, even better, with the historical data (instrumental or not).

In the present work we present the results of a project that was carried out in the National Observatory of Athens, Geodynamic Institute, according to which the historical records for the period 1911–1960 obtained from the mechanical seismographs installed in Athens consist a digital data base, which could be used in studies with the application of modern techniques (ex. spectral analysis). Information is also given on the history of installation and the characteristics of these instruments, and on the utilization of their records since then.

2. Brief History of Mechanical Seismographs in Greece

The work of Comninakis *et al.* (1987) is a good flashback on the installation of the seismographs in Greece up to 1980. The main steps for the mechanical seismographs installed in Greece follow briefly.

Table I. Constants of the seismographs

Time period	Component	Period (s)	Damping ratio	Static magnification	Drumspeed (mm/min)
Mainka seismometer, horizontal components. Mass = 136 kg					
1911–1915	N–E, N–W	6.0	4.7	80	15
1916–1956	N–S, E–W	6.0	4.0	80	15
1957–1963	N–S, E–W	3.5	3.0	60	30
Wiechert seismometer, horizontal components. Mass = 1000 kg					
1924–1949	N–S, E–W	9.2	4	175	12
1950–1953	N–S, E–W	7.2	4	165	30
1954–1963	N–S, E–W	5.0	4	160	30
Wiechert seismometer, vertical component. Mass = 1300 kg					
1928–1949	Z	4.0	3.5	140	10
1950–1959	Z	1.6	1.5	280	30
1960–1963	Z	1.6	1.5	190	30

In 1899 the first, Agamemnon-type, seismograph was installed in the National Observatory of Athens. From a careful examination of the records kept in the National Observatory of Athens it was found that sometime in 1901 another Agamemnon-type started to operate in Kalamata (Southern Greece) and in 1902 two more seismographs of the same type were installed in Chalkida (Central Greece) and in Zakynthos (Ionian Sea, western Greece). It seems that in 1903 the seismograph of Kalamata stopped to operate. There are no records (seismograms or notes) for the period 1904–1910. In 1910 the installation of a Mainka-type, 2-horizontal-component seismograph followed, from which good quality seismograms were obtained. The recording of reliable data started virtually in 1911, when along with Mainka two Agamemnons seems to have operated the one of Athens and another one in Aigio (central Greece). In 1924 the 2-horizontal components of a Wiechert-type seismograph were installed, while the installation of its vertical component was completed in 1928.

From 1957 a more sophisticated seismological instrumentation started with the installation of a short-period Benioff seismograph.

Table I includes the characteristics of the instruments used in this work, which are the two horizontal components of a Mainka seismograph and the vertical and the two horizontal components of a Wiechert seismograph. Values have been taken from the monthly bulletins of the Geodynamic Institute and have been averaged for the respective time periods.

3. Utilization of Historical Seismograms

The seismograms obtained by the MAINKA and WIECHERT seismographs in National Observatory of Athens have been used extensively for determining seismic parameters.

Firstly, their first arrival readings have been used by the international seismological centers for the epicenter and focal depth determination (ISS, BCIS, USGS etc.). Papazachos and Comninakis (1972) published the first complete catalogue of earthquakes in Greece and surrounding area by investigating in detail these seismograms. One more recent catalogue of this type and by the same authors followed (Comninakis and Papazachos, 1986). They have also been used for foreshock and aftershock investigations by several authors (Papazachos *et al.*, 1967; Drakopoulos, 1968; Papazachos, 1974, 1975a, b).

Furthermore, the main advantage for using them is that the instruments were well calibrated during their operation, thus their response curves were well known. That is the reason why an accurate estimation of magnitude formulae from amplitudes and periods could be established (Papazachos and Vasilicou, 1966; Kiratzi and Papazachos, 1984).

4. Usable Seismograms for Greek Earthquakes Occurred During the Period 1911–1960

Table II summarizes the number of the historical seismograms per year and per component, which is usable for further processing. The basic criterion for each seismogram to be included in the table is to be in good shape for further retrieval. The combination of the magnitude with the epicentral distance is critical in overpassing possible rejections of the stylus or such small amplitudes, for which further spectral analysis would give no results due to the low frequency content of the waves recorded. Generally, we started with earthquakes with magnitude $M_s \geqslant 5.0$ and we found quality records from earthquakes with epicentral distances of about 70 kilometers. The stronger the earthquake was, the longer the distance should be. Nevertheless, there was not any strong rule to follow. Some records from earthquakes with smaller magnitudes ($M_s = 4.9$) and with shorter epicentral distances have been especially included in the table, in order to enrich the data during the early years of the seismograph operation. It should be noted that a possible disagreement between this table and a catalog of earthquakes for the same period is due to the fact that either the respective record is missing or has been destroyed by unknown causes, or due to the stylus having been rejected because of the strength of the earthquake.

Figure 1 is a map of the spatial distribution of the epicenters of the earthquakes, whose records have been included in Table II. In total 1825 records of 612 earthquakes passed the criteria for further retrieval.

Table II. Number of the historical seismograms per year and per component, which has been included in the present digital data base

Year	Mn	Me	Wn	We	Wz	Year	Mn	Me	Wn	We	Wz
1911	7	9	–	–	–	1936	3	2	9	10	9
1912	32	25	–	–	–	1937	1	1	3	4	1
1913	7	6	–	–	–	1938	5	4	9	10	9
1914	7	7	–	–	–	1939	–	–	9	7	7
1915	14	13	–	–	–	1940	–	–	7	7	7
1916	12	11	–	–	–	1941	–	–	15	15	14
1917	20	20	–	–	–	1942	–	–	19	19	18
1918	11	11	–	–	–	1943	–	–	11	12	6
1919	13	14	–	–	–	1944	–	–	10	10	7
1920	15	15	–	–	–	1945	1	–	6	5	3
1921	11	10	–	–	–	1946	1	1	5	5	5
1922	20	20	–	–	–	1947	7	7	14	14	13
1923	8	8	–	–	–	1948	7	8	23	23	18
1924	1	–	–	–	–	1949	4	7	8	7	3
1925	9	9	–	–	1	1950	1	1	4	4	4
1926	18	19	–	–	–	1951	4	2	7	8	10
1927	13	11	–	–	–	1952	5	3	15	14	16
1928	9	10	3	3	7	1953	7	6	45	47	50
1929	–	–	9	10	8	1954	5	5	27	28	32
1930	16	16	9	10	8	1955	5	5	8	8	8
1931	10	10	5	5	5	1956	10	9	17	18	18
1932	–	1	16	15	15	1957	8	9	20	22	20
1933	–	–	13	12	12	1958	5	4	9	9	9
1934	–	–	3	3	3	1959	10	9	10	12	11
1935	–	–	5	10	10	1960	4	4	7	7	7

5. Retrieval and Processing of the Historical Seismograms

During the last years the great development of the modern techniques of signal analysis demand the use of digital data. So the necessity of the digitization of analog seismograms has arisen. There are many difficulties in this work. The high velocity of the stylus that leaves the paper or the film unaffected, the clipping of the amplitudes, the bad condition of the records could be mentioned. Especially for the mechanical seismographs which record on smoked paper, the dark background is an additive disadvantage for the original record to be reproduced in any form (contact copy, photocopy, etc.) and to be digitized.

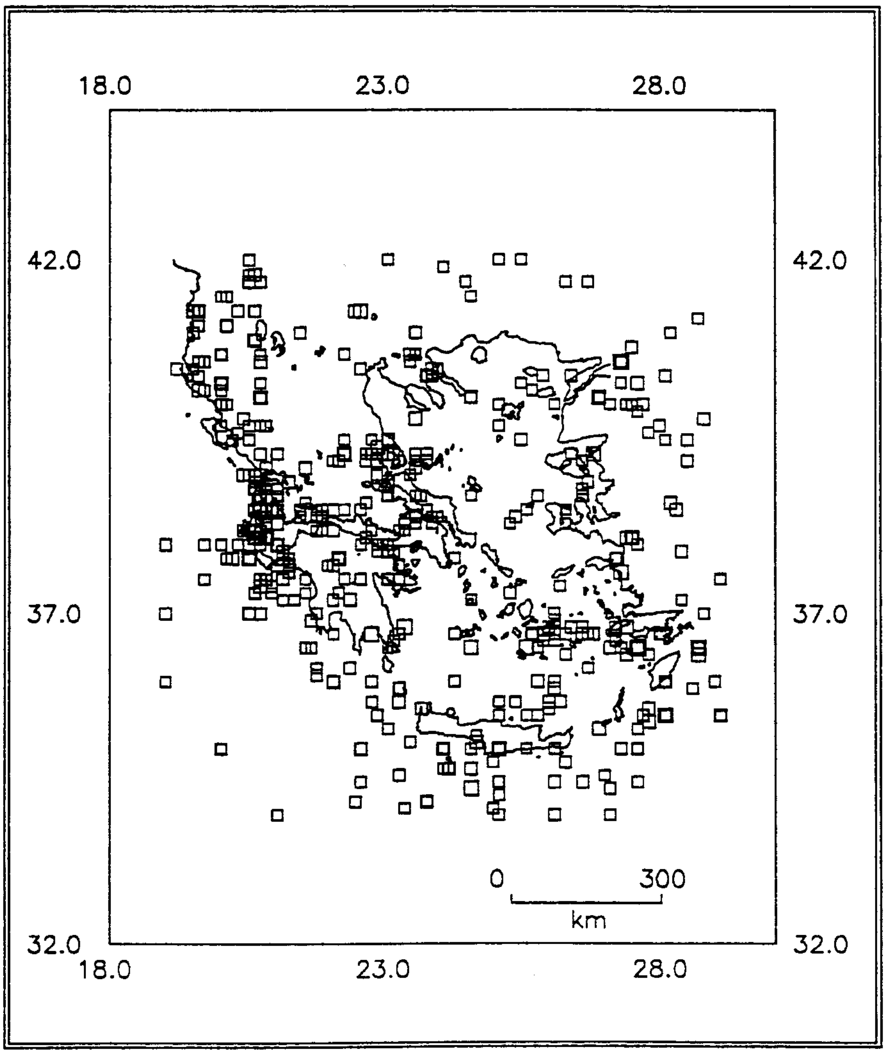


Figure 1. Spatial distribution of the epicenters of the earthquakes, whose records have been included in Table II.

The retrieval processing of the historical seismograms includes three stages: scanning, codification and digitization and saving in ASCII format. Figure 2 illustrates the flow chart of the procedure.

The scanning is made by a system of high capacity personal computers and a high resolution scanner, using a software package for picture processing. At this stage the scanned seismograms are manipulated as black-and-white photographs, with a usual resolution of 1200 dpi. Occasionally, when the picture is of extremely large size, the resolution should be set at 500 dpi. The improvement of the picture follows. This is done in terms of eliminating the zero lines, of homogenizing the

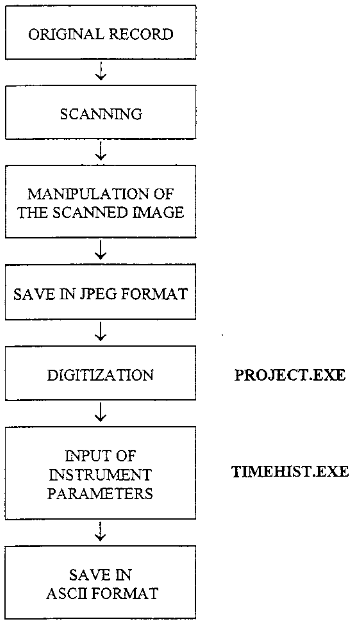


Figure 2. Flow diagram of the procedure followed in the present work.

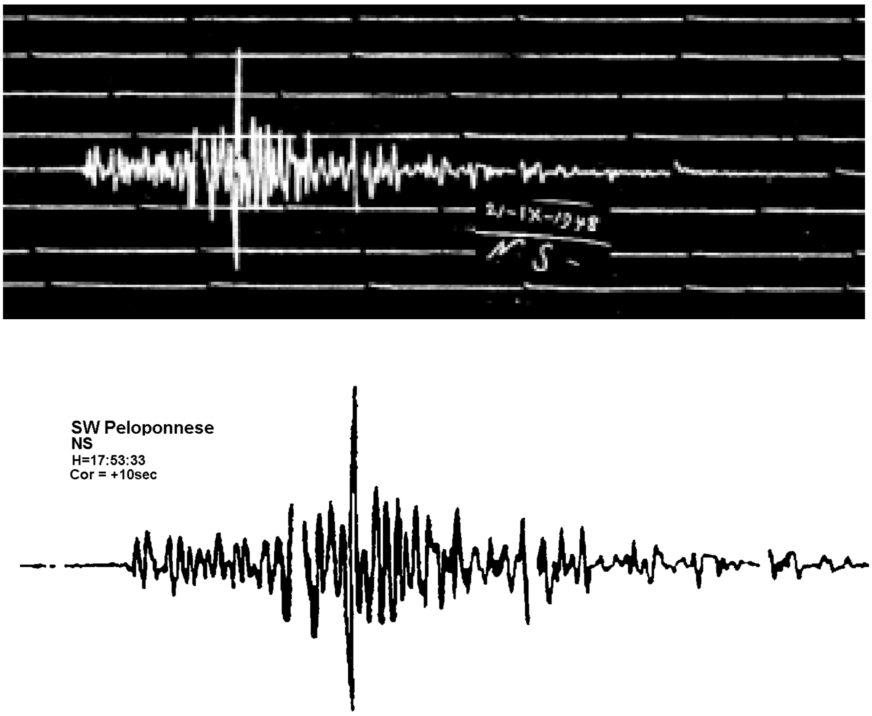
background gray levels and of inverting of the black and white. In the case of Mainka seismograms where the drum was reverse rotated, an additional correction is made, that of the reversing of the seismogram. Figure 3 is a presentation of this first stage, starting from the original seismogram and ending to the processed picture.

Basic information such as the macroseismic epicenter, the identification of the component, the origin time and the time correction are added into the picture. This information along with the code name of the picture, identify the earthquake.

The codification of the picture files follows the rule ABBCCDDE, where A is the component of the seismogram (according to Table III), BB is the last two digits of the year, CC the month and DD is the date. In case that two or more seismograms exist on the record, a latin letter is added, starting from A, indicating the chronological order of the earthquakes. For example the code name 4100321C is dedicated to the third earthquake on the 21 March 1910 recorded by the Mainka N–E /N–S component.

As the picture files are huge (sometimes exceed 10 Mbytes), the compression becomes a necessity. Thus the files are saved in JPEG format (Joint Photographic Experts Group).

The digitization of analog records, even until recently, was applied on the strong motion records. The preparation of the signal for digitization (contact copy and magnification) used to be expensive and, in cases of bad quality of the original, very difficult to be made. On the other hand the semi-automatic digitization enters vari-



(a)

(b)

Figure 3. The retrieval of a historical seismogram starts from the identification of the original record (a) and ends with the processed scanned image (b) as a JPEG picture.

Table III. Seismographs and components with their code numbers used for the codification of the files

Seismographs and components	Code
Wiechert, Z	1
Wiechert, N–S	2
Wiechert E–W	3
Mainka, NE–SW and N–S	4
Mainka, NW–SE and E–W	5

ous errors that affect the final results. These reasons along with the high frequencies that dominate the analog seismograms and the fact that the trace of the earthquake is intersected by the zero lines of the continuous recording of the seismograph did not allow the improvement of methods of semi-automatic digitization and the application of them on the analog seismograms.

The first efforts of semi- or automatic digitization of analog seismograms did not start earlier than this last decade. International literature is limited on this subject. Zama (1992) developed a semi-automatic program of digitizing seismograms.

For the needs of the present project we have developed the necessary software, which consists of two executable programs. The first one (called PROJECT.) is for the conversion of the trace in the picture to cartesian coordinates. It is run under Windows operating system and it has been written in Delphi programming language. If the processing of the scanned image during the first stage has been done correctly, it becomes easier for the user to pick the characteristic points of the trace, by using this program. By picking the points the PROJECT.EXE connects them by a thin line, so the user has the opportunity to compare the digitized trace with the original one during the digitization. The zooming utility allows the user to pick the characteristic points approximately in the middle of the trace. Figure 4 is a working window for this program, in which the characteristic-point picking (digitization) is done with the help of the mouse. It could be said that this digitization procedure is the same as the procedure known as semi-automatic digitization or as optical mechanical digitization. In this procedure the digitizing system consists of a mechanical part with a cross-hair, which is manually set on the point to be digitized, and an analog-to-digital conversion system, which transforms the analog position coordinates of the cross-hair into a digital output. In our case the mouse of the computer plays the role of the cross-hair and the screen plays the role of the digitizing table. The user clicks the mouse on selected points (peaks and inflection points) of the record seen on the screen, at unequal time intervals. The rule the user should follow is to always pick points that lay on the middle of the trace. The points are connected by straight line segments and produce a line which is apparent as a white line (Figure 4).

The second program (called TIMEHIST.EXE) accepts as input file the output of the first program and it is developed for the correction of the obtained file for the instrument parameters (damping ratio, natural period, static magnification and stylus length), for the conversion of the cartesian coordinates to amplitude (mm) and time (sec) and for the storage of the final file in ASCII format. The desirable sampling rate should be entered here. Baseline and curvature correction, as well as the Fast Fourier Transform (FFT) to both direction in order to smooth possible irregularities of the signal, are applied within this program, which has been written in C++ language. Figure 5 presents the procedure sequence of the second program starting with the graphical output of PROJECT.EXE and ending to the corrected trace, with the appropriate units on the axes.

6. Summary

In the National Observatory of Athens, Geodynamic Institute, a unique for Greece and one of the rarest archives of historical seismograms is kept. The high seismicity of the area is the main reason for the historical value of the archive and for the huge

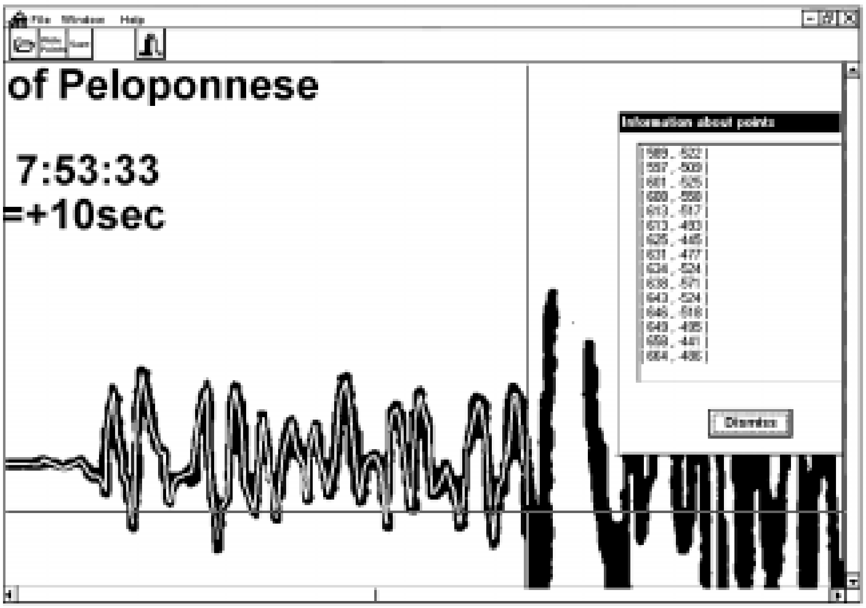


Figure 4. Working window of the PROJECT.EXE computer program. The center of the cross-hair corresponds to the picking point.

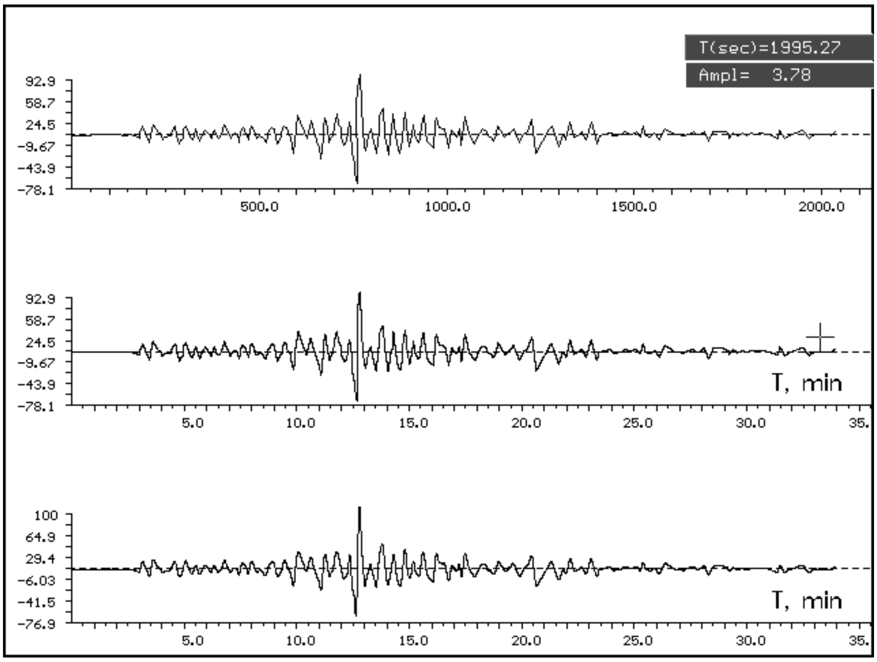


Figure 5. Graphical presentation of the TIMEHIST.EXE computer program, starting with the output of the PROJECT.EXE at the top and ending with the graph of the ASCII file (output of the TIMEHIST.EXE) at the bottom.

amount of data. To ensure secure storage conditions for this archive, along with the utilization of the records in research studies with the application of modern techniques, the necessity of the development of a software for raster to vector conversion of these seismograms was generated.

This study is a first approximation to the above mentioned aim. The seismograms examined and converted into digital format cover the time period 1910–1960. The operation of the mechanical type seismographs of the National Observatory of Athens continued till the end of the previous decade, thus the data base should be enriched. The usefulness of such a kind of data base is obvious. Modern techniques of spectral analysis that were applied to the data recorded in various periods, during which the operation of seismological instruments was limited, can be correlated with the conclusions based on recently obtained digital data.

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References

Comninakis, P., Drakopoulos, J., and Papazachos, B.: 1987, Historical seismograms in Greece, *Gerlands Beitr. Geophysik, Leipzig* **96**, 416–422.

Comninakis, P. E. and Papazachos, B. C.: 1986, *A Catalogue of Earthquakes in Greece and the Surrounding Area for the Period 1910–1985*, Publ. Geophys. Lab. Univ. Thessaloniki, Vol. 1.

Drakopoulos, J.: 1968, Characteristic parameters of fore- and aftershock sequences in the area of Greece, PhD Thesis, University of Athens.

Kiratzi, A. A. and Papazachos, B. C.: 1984, Magnitude scales for earthquakes in Greece, *Bull. Seism. Soc. Am.* **74**, 969–985.

Papazachos, B. C.: 1974, On certain aftershock and foreshock parameters in the area of Greece, *Annali di Geofisica* **27**, 497–515.

Papazachos, B. C.: 1975a, Aftershock and foreshock sequences in the area of Greece during the period 1911–1973, *Bull. Gr. Space Res.* **3**, 1–36.

Papazachos, B. C.: 1975b, Foreshocks and earthquake prediction, *Tectonophysics* **28**, 231–236.

Papazachos, B. C. and Comninakis, P. E.: 1972, The seismic activity in the area of Greece during the time period 1911–1971, *Publ. Sci. Group Space Res., Greece* **4**, 1–60.

Papazachos, B. C., Delibasis, N., Liapis, N., Moumoulidis, G., and Purkaru, G.: 1967, Aftershock sequences of some large earthquakes in the region of Greece, *Annali di Geofisica* **20**, 1–93.

Papazachos, B. C. and Vasilikou, A.: 1966, *Studies on the Magnitude of Earthquakes*, Progress Report in Seismology and Physics of the Earth's Interior, Greece.

Zama, S.: 1992, On a system to digitize analog seismogram, *Report of Fire Research Inst. of Japan* **74**, 1–7.