HEAD 1.0: A Unified HEllenic Accelerogram Database

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INTRODUCTION

During the past thirty years various accelerogram data sets recorded by "free field" strong-motion stations in Greece have been compiled by two institutes that are in charge of running national strong-motion networks. These data sets have been of limited potential use for research because of nonstandard processing, nonhomogeneous earthquake parameters adopted, and a minimum standard of site characterization based only on surface geology. In addition, given an ever-increasing cumulative number of accelerograms, a database was required to facilitate data selection by users. To satisfy all these issues we have developed HEAD version 1.0—a unified HEllenic Accelerogram Database—which is briefly presented in the present paper. Homogeneous strong-motion data processing and site characterization based on detailed borehole data or/and Vs profiles allow the data to be used to their full potential. Instrument and housing characteristics are provided for each station, and relocated earthquake hypocenter parameters and moment-magnitude are given for each earthquake.

Understanding the nature of strong ground motion is of crucial importance in reducing seismic risk worldwide. Publication of strong-motion data is essential for development of building codes and design methods for large engineering structures as well as for development of near-field seismology. After realizing the need for organized strong-motion data sets, the scientific community has developed user-friendly databases (among others, Kinoshita, 1998; Steidl and Lee, 2000; Ambraseys *et al.*, 2002; LDEO/NCEER, 2003). In Greece, deployment of a strong-motion network began in the early 1970's under the auspices of the Geodynamic Institute (GEIN) of the National Observatory of Athens; ten years later the Institute of Engineering Seismology and Earthquake Engineering (ITSAK) began an effort to install a new strong-motion network throughout Greece. Prior to 2000 the vast majority of strong-motion instruments of the national network were analog (SMA-1 Kinemetrics). In recent years, analog recorders have begun to be replaced by a new generation of digital instruments.

Strong-motion data released in Greece during the last two decades have come from GEIN and ITSAK (Stavrakakis *et al.*, 1992; Kalogeras and Stavrakakis, 1995, 1998, 1999; ITSAK, 1997, 1999). A first effort to construct a strong-motion database for educational and research purposes was made using GEIN data (Kalogeras, 2002). Although both institutes made serious efforts to publish important data sets, inconsistent data processing methods made it difficult to exploit the data to their full potential. On the other hand, automatic digitization using a simple hardware configuration (PC, color scanner) and appropriate software (Kinemetrics, 1990) facilitated analog data processing during the last decade. Furthermore, a noise-level study allowed for realistic low- and high-pass filter selection, thus providing homogeneously corrected strong-motion data.

In this paper we present a first effort toward a unified accelerogram database including records from the Greek (Hellenic) strong-motion network, after reprocessing all records with the same procedure. This first version of the database (HEAD 1.0) is designed to be open to future data input and possible modifications serving the scientific and engineering communities.

STRONG-MOTION NETWORK & DATA SELECTION

The national strong-motion network in Greece consists of accelerographs permanently installed at selected sites, mainly within residential centers or industrial areas. The majority of instruments (about 75%) are installed in the free field and in the basements or ground floors of one- to three-story buildings; the rest are installed in the basements of higher buildings.

The first strong-motion network (GEIN) in Greece had a relatively small number (~20) of accelerographs. This early network recorded several moderate to large magnitude earthquakes in Greece, some of them damaging (Lefkas, M 5.8, 1973; Thessaloniki, M 6.5, 1978; Corinth, M 6.8, 1981). After the establishment of ITSAK, another 50 accelerographs were installed in the early 1980's, providing an extended strong-motion network throughout Greece. The deployment of additional accelerographs was mainly based on the study of Theodulidis *et al.* (1986). Today, the national strong-motion

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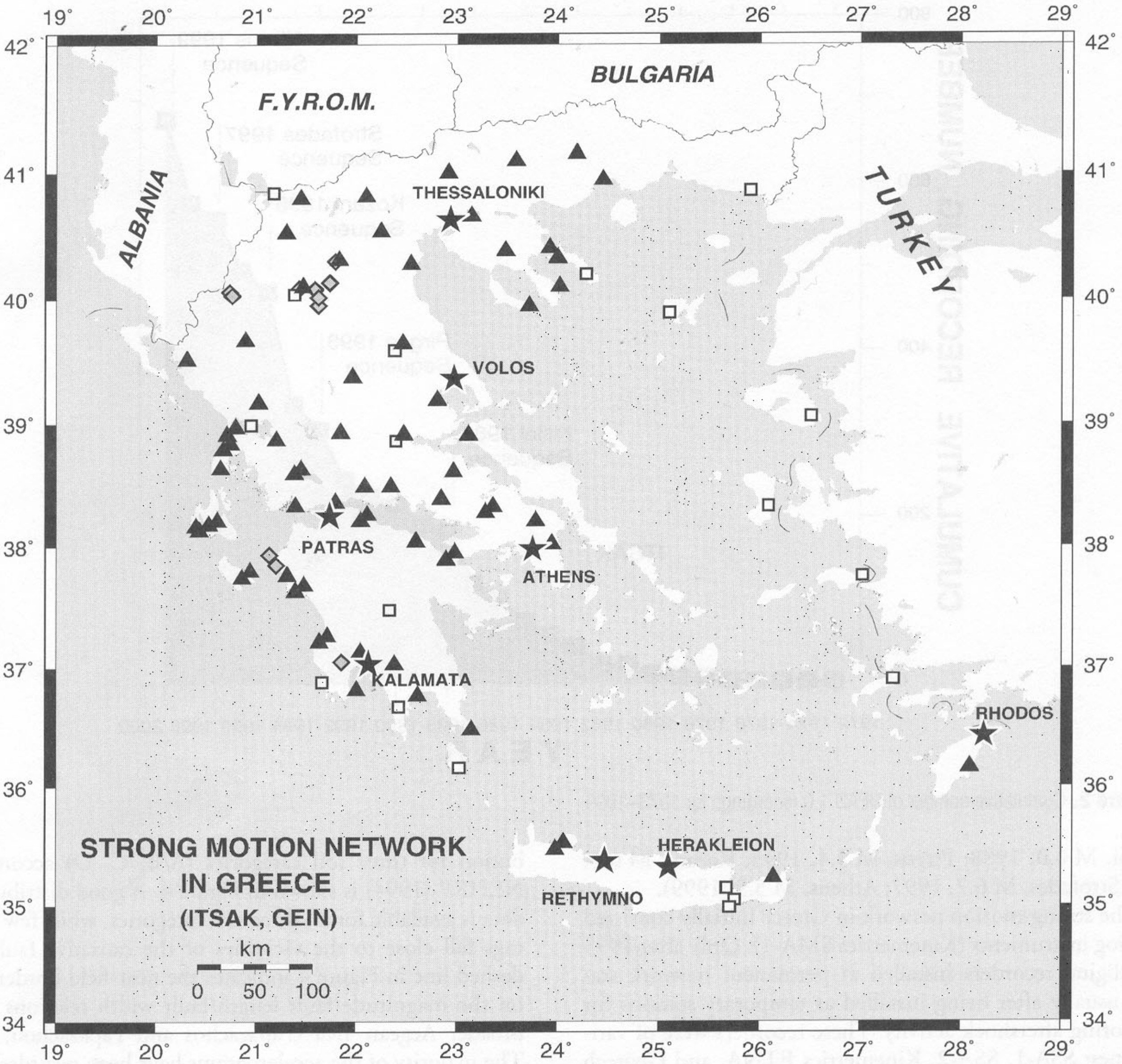


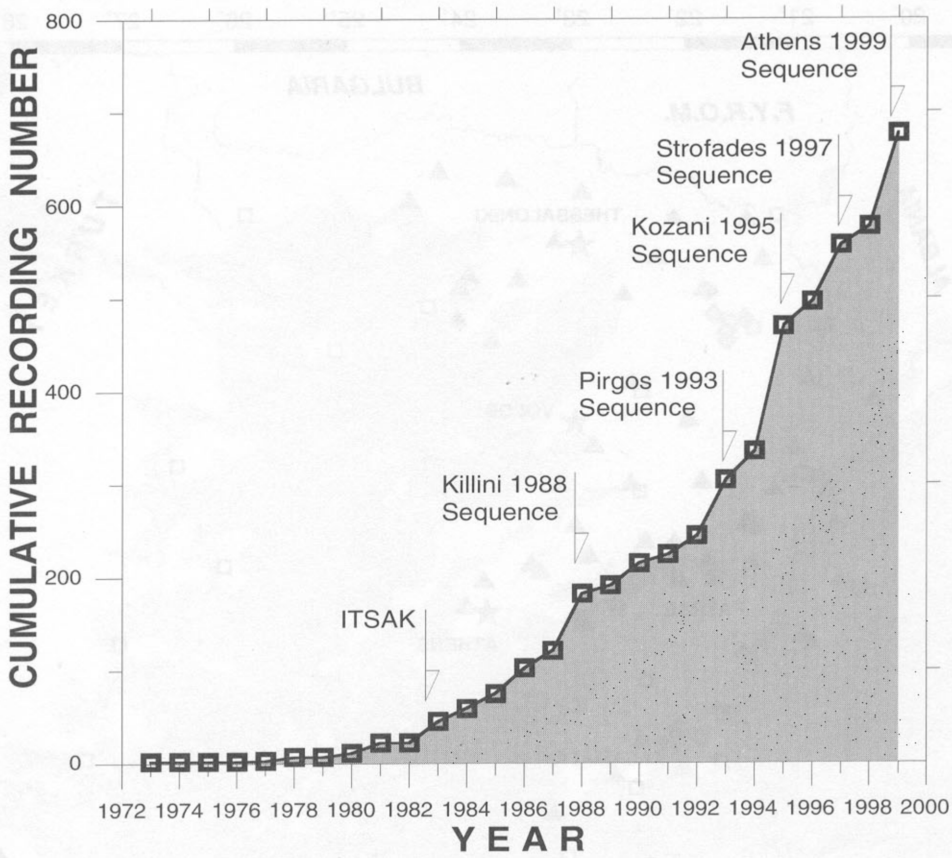
▲ **Figure 1.** Free-field accelerograph stations in Greece (stars: sites with more than three instruments; triangles: single-station sites; open squares: single station sites not yet triggered; gray diamonds: single stations temporarily deployed and already removed).

network in Greece consists of about 120 accelerographs operated by the aforementioned institutes (Figure 1).

Data included in HEAD 1.0 come from ITSAK and GEIN's accelerograph networks operating for a period of twenty-seven years, namely from 1973 to 1999, with the vast majority of records coming from analog accelerographs. After the year 2000, data come mainly from digital instruments and will be a supplement of the database in the near future, together with all possible corrections. From all available recordings only those conforming with the following complementary criteria were processed and incorporated in HEAD 1.0:

- The earthquake which produced the accelerogram must have an equivalent moment magnitude $M \geq 4.5$, or
- The accelerograph recording must have peak ground acceleration $PGA \geq 0.05$ g, or
- The record can have peak ground acceleration $PGA < 0.05$ g but corresponds to the same earthquake with another record with $PGA \geq 0.05$ g.

Following the aforementioned criteria, 677 recordings were digitized, processed, and included in the database. In Figure 2 the cumulative number of accelerograms versus time period from 1973 to 1999 is shown. It is evident that the installation of additional accelerographs by ITSAK significantly increased the number of recordings after 1983. In addition, five high-rate "steps" are observed due to corresponding seismic sequences that occurred in Greece during the last two decades



▲ **Figure 2.** Cumulative number of HEAD 1.0 recordings for 1973–1999.

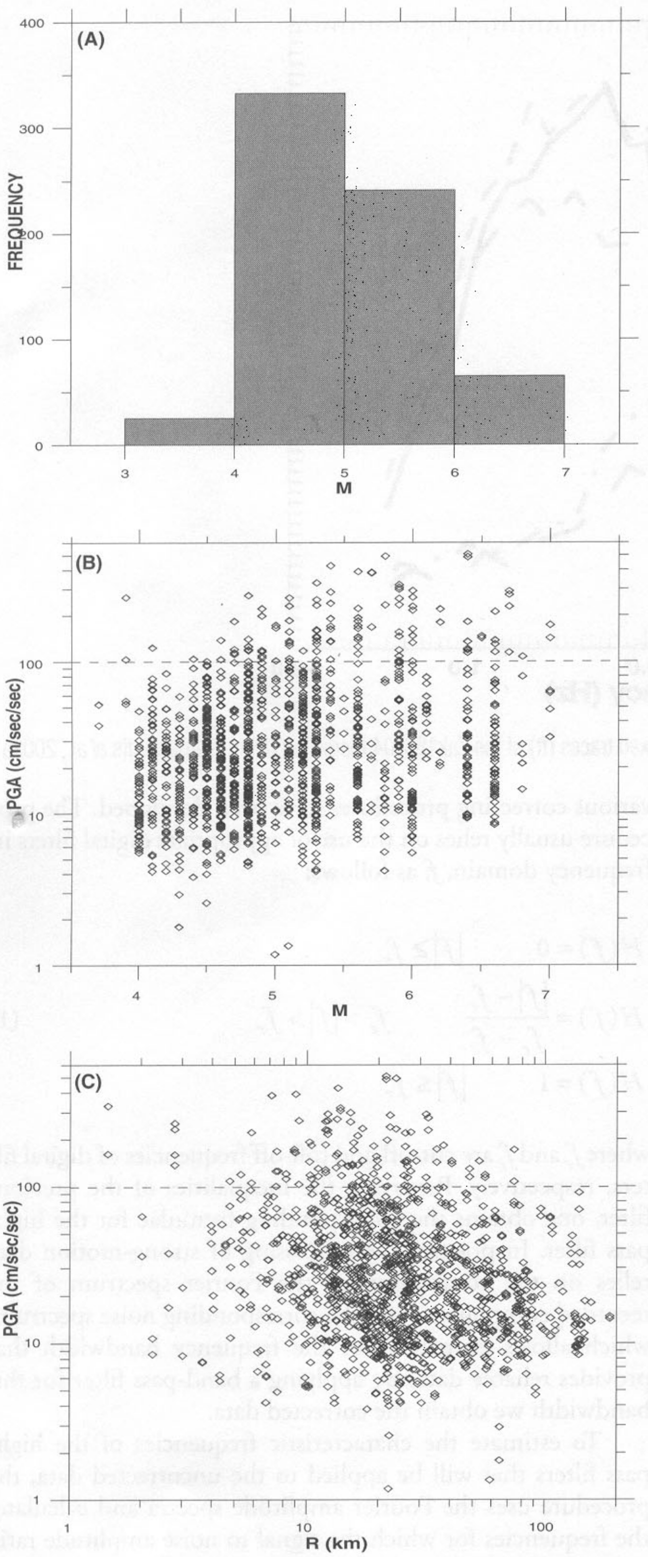
(Killini, M 6.0, 1988; Pirgos, M 5.4, 1993; Kozani, M 6.6, 1995; Strofades, M 6.7, 1997; Athens, M 5.9, 1999).

The strong-motion network in Greece initially consisted of analog instruments (Kinemetrics SMA-1). Only after 1995 were digital recorders installed at permanent network stations, usually after being installed as temporary stations for monitoring aftershock activity. These recorders were of various types: SSA-1, SSA-2, Kinemetrics ETNA, and Geotech A-800. During the last three years the majority of the national strong-motion network analog recorders have been replaced by digital ones (Kinemetrics QDR), upgrading the whole network and allowing for remote control dial-up telemetry. New-generation digital recorders provide remote control, facilitating maintenance and diagnostics and increasing network readiness.

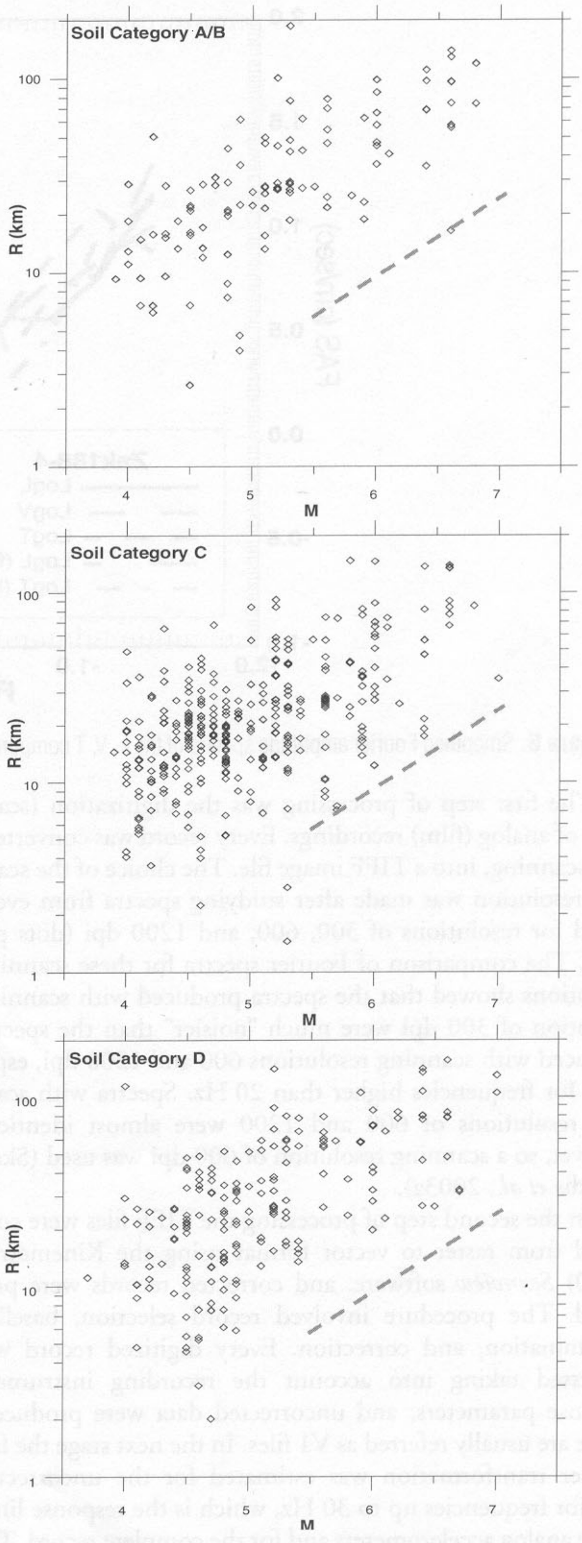
The original analog strong-motion network was maintained regularly twice a year by specialized technicians. During the last thirty years all large earthquakes—most of them damaging—in Greece have been recorded successfully by the national network. Figure 3 shows the magnitude and epicentral distance distributions of strong-motion data included in HEAD 1.0. About half of the recordings come from earthquakes with magnitude $M \geq 5.0$. About 10% of the recordings have peak ground-acceleration values above 0.1 g, coming mainly from magnitudes $M \geq 5.0$ and epicentral distances $R \leq 50$ km. Magnitude-epicentral distance data distribution for three soil categories (A/B, C, D) according to NEHRP (1994) is shown in Figure 4. A good distribution of data is available for all three soil categories, while few recordings fall close to the vicinities of the causative faults. The dashed line in Figure 4 indicates the near-field borders based on the magnitude/fault length/fault width relations for the broader Aegean area (Papazachos and Papazachou, 1997). The majority of the accelerograms have been recorded at epicentral distances less than 100 km.

DATA PROCESSING

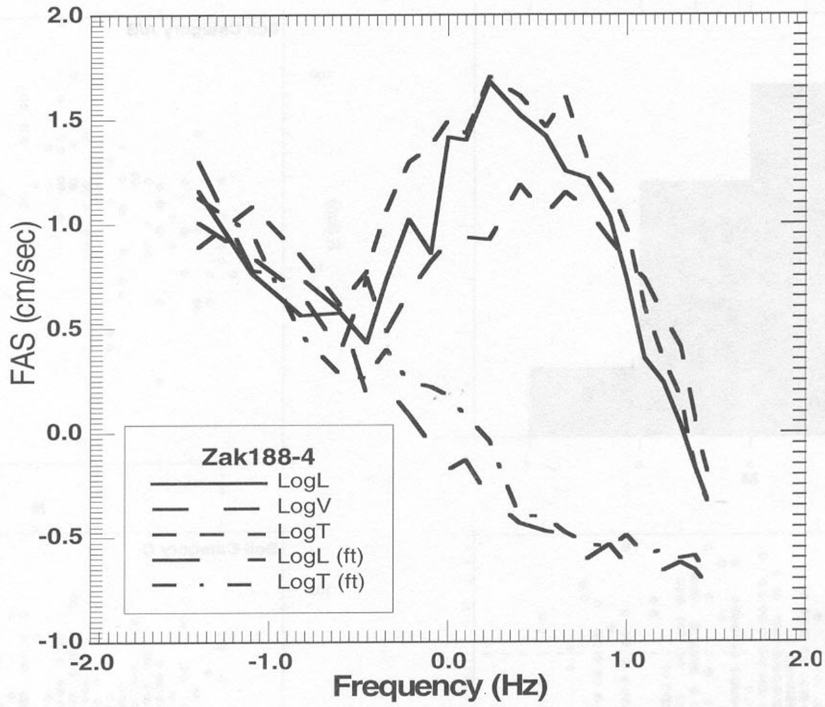
Data recorded by analog SMA-1 instruments must be digitized with a semiautomatic or an automatic procedure. When comparing processed data from analog machines with those from digital accelerographs, significant noise introduction in the former ones has been observed, mostly in lower frequencies. This noise is produced by the digitization process itself and results in a smaller frequency bandwidth for which reliable information can be obtained compared to data recorded on digital accelerographs (Trifunac and Lee, 1974; Margaris, 1994; Skarlatoudis *et al.*, 2003a). To reduce noise level in the digitized accelerograms of HEAD 1.0, as much as possible, all data for 1973 to 1999 were reprocessed with the procedure described below.



▲ **Figure 3.** HEAD 1.0 data distribution plots: (A) magnitude histogram frequency, (B) magnitude-PGA, (C) epicentral distance-PGA.



▲ **Figure 4.** HEAD 1.0 magnitude-epicentral distance data distribution for three soil categories. Dashed line indicates near-field borders based on magnitude/fault length/fault width relations for the broader Aegean area (Papazachos and Papazachou, 1997).



▲ **Figure 5.** Smoothed Fourier amplitude spectra of the L, V, T components and fixed traces (ft) of the Zak188-04 recording (from Skarlatoudis *et al.*, 2003a).

The first step of processing was the digitization (scanning) of analog (film) recordings. Every record was converted, after scanning, into a TIFF image file. The choice of the scanning resolution was made after studying spectra from every record for resolutions of 300, 600, and 1200 dpi (dots per inch). The comparison of Fourier spectra for these scanning resolutions showed that the spectra produced with scanning resolution of 300 dpi were much "noisier" than the spectra produced with scanning resolutions 600 and 1200 dpi, especially for frequencies higher than 20 Hz. Spectra with scanning resolutions of 600 and 1200 were almost identical, however, so a scanning resolution of 600 dpi was used (Skarlatoudis *et al.*, 2003a).

In the second step of processing the TIFF files were converted from raster to vector format using the Kinemetrics (1990) *Scanview* software, and corrected records were produced. The procedure involved record selection, baseline determination, and correction. Every digitized record was processed taking into account the recording instrument response parameters, and uncorrected data were produced. These are usually referred as V1 files. In the next stage the fast Fourier transformation was estimated for the uncorrected data for frequencies up to 30 Hz, which is the response limit of the analog accelerometers and for the complete record. The same procedure also was applied to the digitized fixed traces. For the noise study the smoothed Fourier amplitude spectra (FAS) of the components and the corresponding fixed traces of the record were compared, as is shown for the ZAK188-04 record in Figure 5.

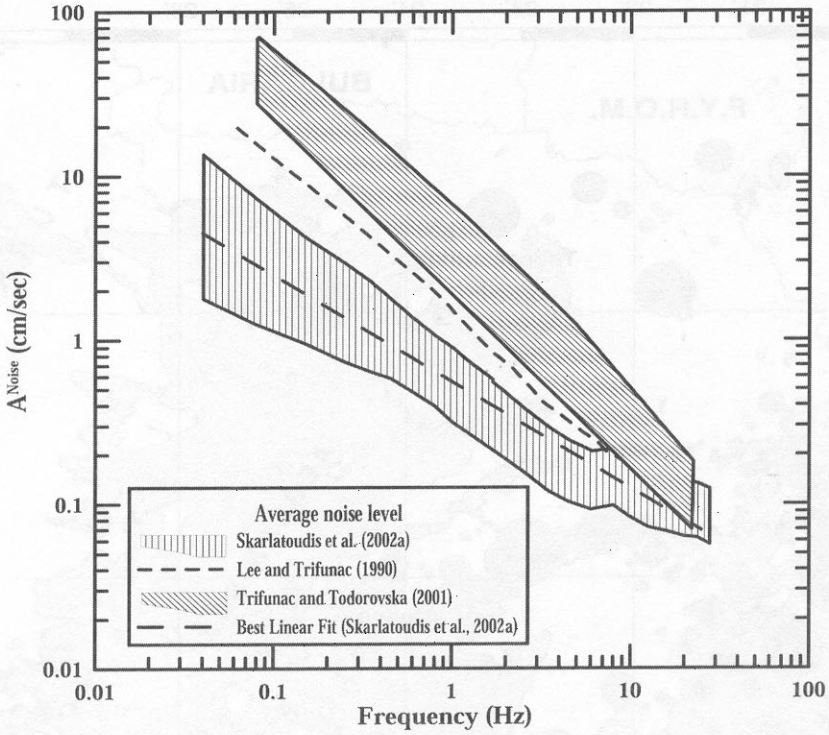
To remove all possible errors and reliably determine ground parameters (acceleration, velocity, and displacement), various correcting procedures have been developed. The procedure usually relies on the use of appropriate digital filters in frequency domain, f, as follows:

$$\begin{aligned} H(f) &= 0 && |f| \geq f_c \\ H(f) &= \frac{|f| - f_c}{f_r - f_c} && f_c > |f| > f_r \\ H(f) &= 1 && |f| \leq f_r \end{aligned} \qquad (1)$$

where f_c and f_r are cut-off and roll-off frequencies of digital filters, respectively. Reverting the inequalities of the previous filter, one obtains the corresponding formulae for the high-pass filter. In practice the processing of strong-motion data relies on the comparison of the Fourier spectrum of the recorded components and the corresponding noise spectrum, which allows estimation of the frequency bandwidth that provides reliable data. By applying a band-pass filter for this bandwidth we obtain the corrected data.

To estimate the characteristic frequencies of the high-pass filters that will be applied to the uncorrected data, the procedure uses the Fourier amplitude spectra and calculates the frequencies for which the signal to noise amplitude ratio is 2:1, 3:1, etc. After testing different filters for the records, we chose for cut-off frequency f_c, the frequency where signal to noise ratio was greater than 2, and for roll-off frequency f_r, the frequency where signal to noise ratio was greater than 3 (Skarlatoudis *et al.*, 2003a).

The characteristic frequencies of the high-pass filters were calculated for every record with the method discussed



▲ **Figure 6.** Average spectral noise curves of Hellenic data in comparison with corresponding noise curves in USA (modified from Skarlatoudis *et al.*, 2003a).

above. For the low-pass filters the characteristic frequencies of 25 and 27 Hz were used for most records in accordance with the frequency response of the accelerometer. This rule of thumb was not applied in only a few cases where we observed an intense reduction of the signal in high-frequency amplitudes. By applying the previously discussed filters, with the use of the proper software (Skarlatoudis *et al.*, 2003a), we obtained the corrected data, usually referred to as V2 files.

For records where no fixed trace (reference trace on SMA-1 film recordings) was available, an average noise spectrum based on all smoothed fixed traces of the recordings was adopted. Figure 6 shows the average spectra noise level. The standard deviation, the best linear fit, and the corresponding curves produced by Lee and Trifunac (1990) and Trifunac and Todorovska (2001) are also shown. One can observe that the average noise level approximately follows a linear law with a negative slope, which corresponds to the equation (Skarlatoudis *et al.*, 2003a)

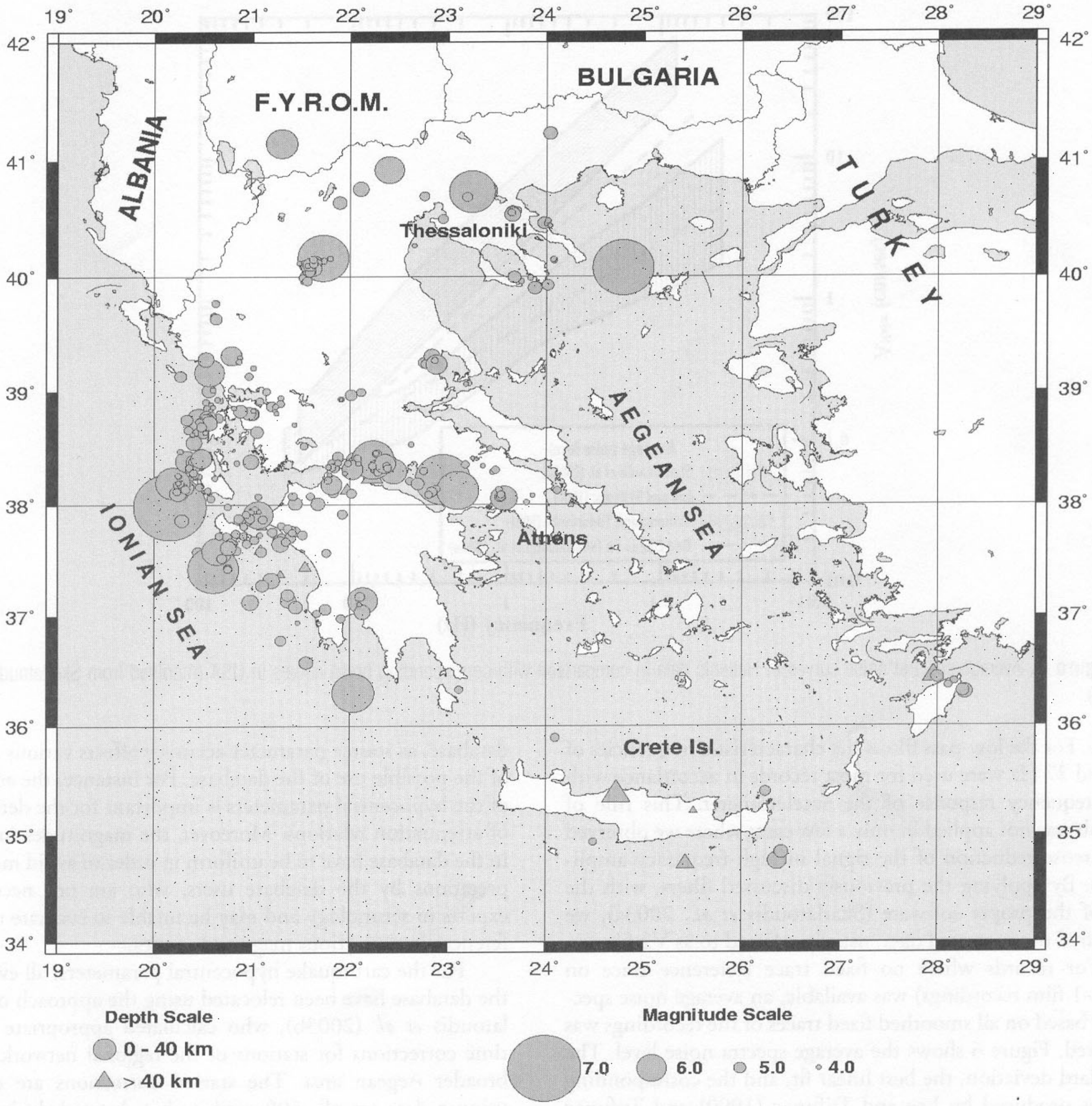
$$\log A^{Noise} = -0.65 \times \log f - 0.25, \qquad (2)$$

which has a linear correlation coefficient $r = 0.99$ and standard deviation $\sigma = 0.067$.

SEISMOLOGICAL AND SITE INFORMATION

A critical point in the construction of a strong-motion database is the quality of hypocentral parameters, included in the database, as source parameter accuracy affects various aspects of the possible use of the database. For instance, the accuracy of the hypocentral parameters is important for the derivation of attenuation relations. Moreover, the magnitudes included in the database have to be uniform in order to avoid misinterpretations by the database users, who are not necessarily experts in seismology and may be unable to evaluate the differences in the various magnitude scales.

For the earthquake hypocentral parameters, all events in the database have been relocated using the approach of Skarlatoudis *et al.* (2003b), who calculated appropriate travel-time corrections for stations of the regional network of the broader Aegean area. The station corrections are derived using a data set of ~600 earthquakes, located during local seismicity and aftershock activity monitoring experiments, which had also been recorded by the permanent regional seismological networks. Based on this high-accuracy earthquake data set, as recorded by dense local arrays, an effort to also improve location accuracy of the regional network was made. For this purpose ~3,000 time residuals of arrivals from these local earthquakes to the regional network have been estimated with respect to a regional 1D model (Panagiotopoulos and Papazachos, 1985). These residuals were used in a robust inversion procedure to compute appropriate corrections for a grid of 1° spacing covering the broader Aegean area. Relocation of the local earthquake data set used in the analysis by the application of the previously estimated corrections has shown significant improvement (Skarlatoudis *et al.*, 2003b), especially for depth estimates, when using arrivals only from



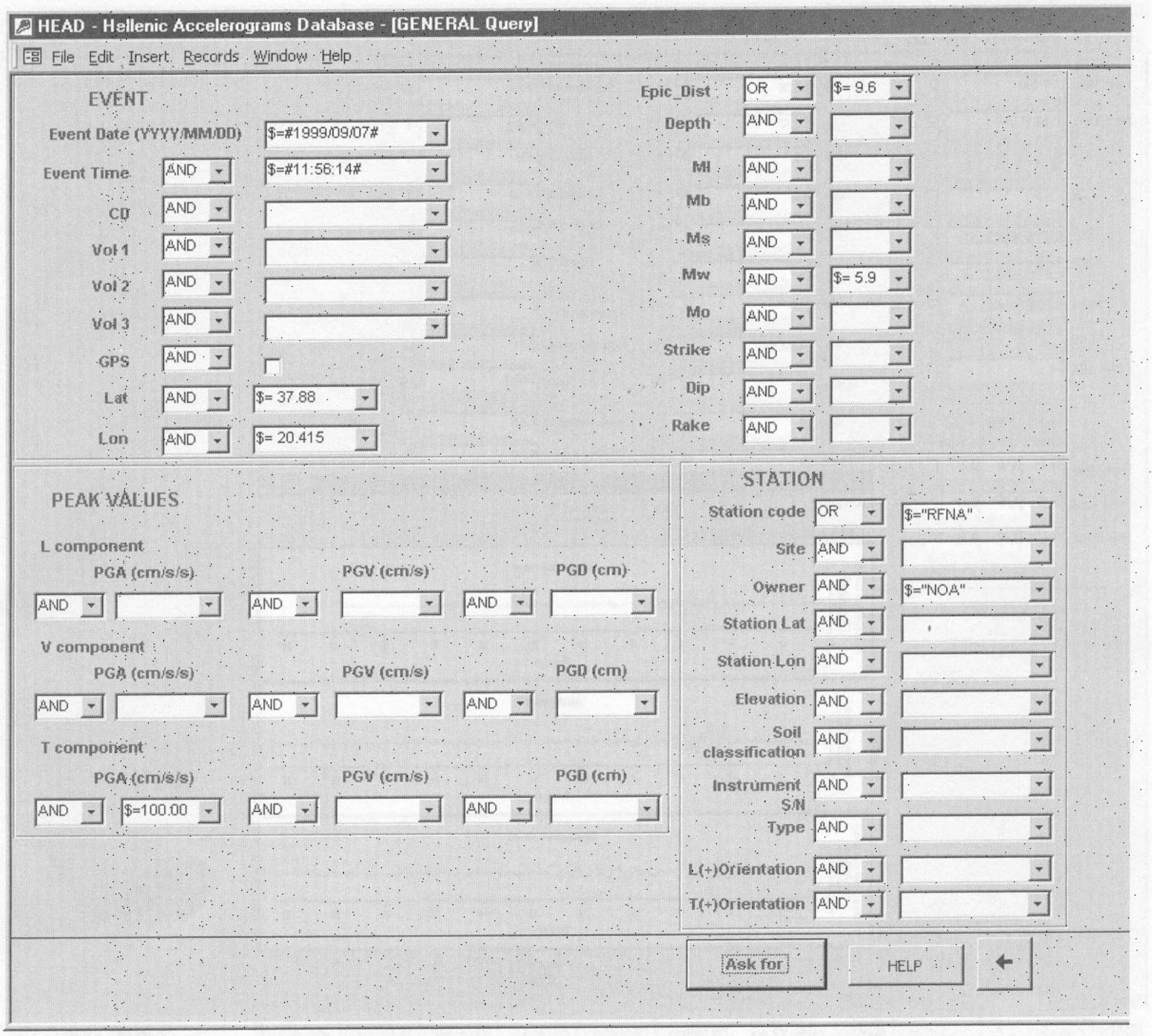
▲ **Figure 7.** Relocated epicenters of HEAD 1.0 earthquakes.

the regional seismological network, as is the case for the database earthquakes.

For the database, hypocentral parameters for a small subset of earthquakes (~10%) were collected from various published papers; these were usually high-precision locations from temporary arrays deployed during aftershock sequences, which can be considered as high accuracy (typical hypocentral error ≤ 5 km). The remaining events were relocated using the previously described procedure from the regional network arrival times. The final epicenter distribution is shown in Figure 7.

The earthquake magnitudes included in the database are originally reported moment magnitudes, when such information was available from international centers (usually Harvard CMT and USGS determinations) or published work on individual events. When that information was not available, we have used equivalent moment magnitudes converted by appropriate relations derived for the Aegean area, mainly from local (M_L) magnitudes (Papazachos *et al.*, 1997, 2002; Margaris and Papazachos, 1999). Hence, to the extent possible the earthquakes included in the database have a homogeneous magnitude scale (original or converted moment magnitudes), which can be used for any research or engineering purpose (attenuation of peak or spectral values, etc.).

Regarding site information, an effort was made to include in HEAD 1.0 detailed geotechnical information. Vs profiles to a depth of about 30 m were available for only fif-



▲ **Figure 8.** HEAD 1.0 general query form.

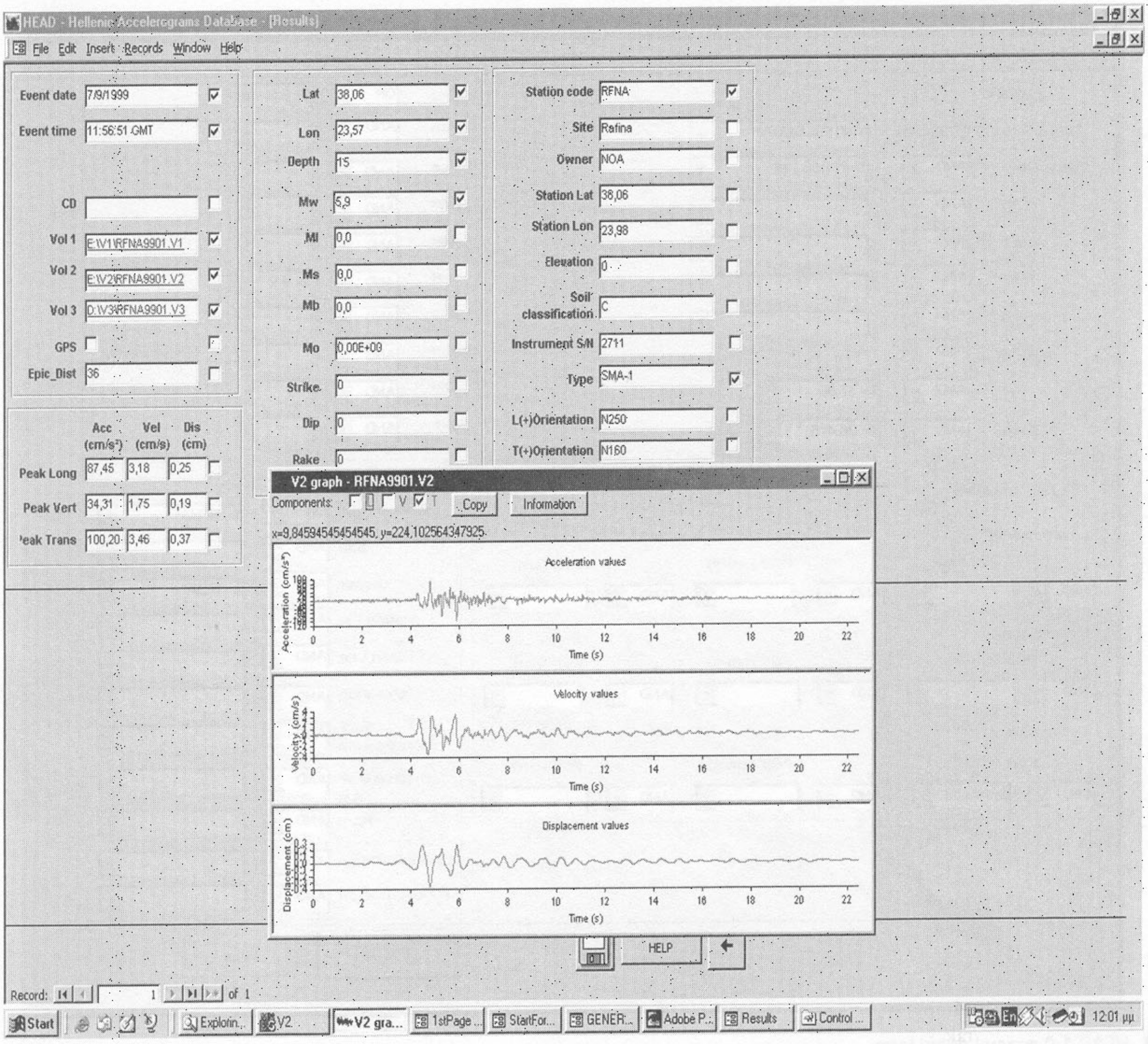
teen strong-motion stations. For the rest of the stations either borehole data at distance of less than a few tens of meters close to the station or surface geology descriptions from geological maps (IGME, scale 1:50.000) are included. General information about stations (instrument type, housing building, coordinates, etc.) is also presented. Where available, average macroseismic intensity based on the modified Mercalli scale is included, as it is given by the GEIN monthly bulletins for the time period 1973 to 1999. The earthquake, station, and recording information for earthquakes with $M \geq 5.0$ are available at http://www.gein.noa.gr/HEAD or at http://www.itsak.gr/HEAD.

DATABASE STRUCTURE

The HEAD database was designed to be a user-friendly system for acquiring accelerogram records of Hellenic region earthquakes using any possible criterion for events, stations, or results of the data processing or acquisition. The database is *MS Access*–based and was designed to provide a convenient way to download all of the data files (uncorrected or corrected) according to the user's inquiry.

The design of the HEAD database was based on four main data tables. The tables are related to each other with "one to many" relationships with "referential integrity" and "cascaded updating of the related fields" in order to increase speed and facilitate expandability. The four basic tables have been named according to the information they contain: (a) accelerogram records (40 information fields), (b) station (15 information fields), (c) event (15 information fields), and (d) instrument (12 information fields). In addition to these, additional tables have auxiliary roles, several SQL queries, forms, macros, and Visual BASIC modules. All these support a user-friendly interface (graphical user interface or GUI), which is what finally a user sees (Figure 8). The aforementioned technical terms concerning the database structure and operation can be found in Prague (1999).

In the database the functionality of the hypertext was employed in an effective way. In particular, all the filenames are written in hypertext. When activated in a viewer program a file is automatically loaded, presenting the required files



▲ **Figure 9.** A typical screen resulting from the "general query" form. User can select the appropriate boxes and save the selected information in an *Excel®* table. An option for graphical viewing and saving of uncorrected data, corrected data, and response spectra (PSA, PSV, PSD) for all components and damping factors is also available.

graphically (Figure 9). The database also has graphical representations of the spatial distribution of recorded earthquakes and recording stations.

DISCUSSION

Construction of HEAD 1.0 is an initial effort to present a unified strong-motion data set from the national strong-motion network in Greece for the period 1973 to 1999. Since the vast majority of recordings included in this database come from analog accelerometers, homogeneous data processing performed using realistic low- and high-pass filters rendered it useful for both research and engineering purposes.

It is well known that detailed site characterization significantly increases the potential utility of strong-motion records. For this reason all available geotechnical data for each recording station were included in the database, allowing users to perform their own characterization and site selection. A preliminary site characterization according to NEHRP 1994 (A, B, C, D, E) is also included. Unfortunately, a Vs profile is available for only a small percentage, about 15%, of the strong-motion station sites. This highlights the need for an extended site characterization of accelerometer sites in Greece in order to exploit recordings to their full potential.

The lack of near-field strong-motion data is evident in HEAD 1.0 (Figure 4). This shortcoming reflects the sparsity of strong-motion instruments in Greece. Recently, through a national project, almost all strong-motion instruments constituting the national network have been replaced or upgraded with digital ones. This may significantly improve future HEAD versions with better quality and high-resolution digital data. In addition, denser networks in areas of higher seismicity may also increase the probability of acquiring near-field recordings. Remote control capability of digital recorders, which is available now, will certainly improve the functionality of the national strong-motion network and assure prompt information for local authorities after a strong earthquake by providing recorded strong-motion values.

HEAD 1.0 is the first effort to create a unified accelerogram database in Greece. It is open to future developments or/and modifications by the participating institutions. HEAD 1.0 will be available to any interested institution, researcher, or engineer at the Web sites http://www.itsak.gr and http://www.noa.gein.gr.

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