A Review of the Greek Strong Motion Database: Needs, Improvements and Future Development

Segou M(1), Voulgaris N(2), Makropoulos K(3), Stavrakakis G(4)

(1) Department of Geophysics-Geothermics, Faculty of Geology and Geoenvironment, National and Kapodistrian University of Athens, msegou@geol.uoa.gr
(2) Department of Geophysics-Geothermics, Faculty of Geology and Geoenvironment, National and Kapodistrian University of Athens, voulgaris@geol.uoa.gr
(3) Department of Geophysics-Geothermics, Faculty of Geology and Geoenvironment, National and Kapodistrian University of Athens, kmacrop@geol.uoa.gr
(4) Institute of Geodynamics, National Observatory of Athens, g.stavr@gein.noa.gr

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Introduction

During last decades the rapid progress of strong motion seismology and earthquake engineering practice lead to an increasing number of seismic hazard studies. The multi-parametric nature of these studies implies that the development observed so far is related to a number of components; technical ones such as modern strong motion instruments operation and personal computer's increased processing power, or analytical ones, related with the overall evaluation of the strong ground motion, the advances in processing techniques applied at a the significant number of strong motion recordings and new insights related with seismic rupture propagation.

In this paper we will focus on the importance of the strong motion database itself since it provides the basic seismological data for any seismic hazard study. The paradigm of the Greek strong motion database is a difficult one since it is quite inhomogenous and only few decades long. Since the early 70's strong motion seismology made important steps; mainly analogue recordings provide strong motion data from destructive earthquakes until late 90's when digital instruments replace a number of analogue accelerographs. However the population of the digital instruments is far from being adequate for a country of high seismic risk as Greece.

Concerning digital instruments, some deficiencies observed to certain types of instruments are pointed out and the role of good quality strong motion records, in terms of earthquake and engineering seismology practice, is discussed through the paper.

A secondary purpose of the paper is to introduce the future user of any strong motion database to criteria, for choosing between existing databases and among strong motion records of a unique database, depending on the researcher's needs.

Materials and Methods

The Greek Reprocessed Strong Motion Database (GReD) is a part of the Reprocessed Strong Motion Database (ReD), since the latter contains reprocessed data from around the world.

At the first stages of the GReD' s development a number of 410 analogue strong motion records, provided by Greek institutions, were peer reviewed through the visual inspection of their uncorrected time series in order to make an initial assessment of their quality.
The number of analogue records included finally in GReD corresponds, to 35% of the total number of analogue records primarily inspected, with instrument operator for the selected records being the National Observatory of Athens.

GReD consists of 151 three component analogue (Stavrakakis et al. 1992, Kalogeras & Stavrakakis, 1995, Kalogeras & Stavrakakis, 1998) and 70 digital records (Kalogeras & Stavrakakis, 1999, Kalogeras & Stavrakakis, 2007) of major earthquakes of Greece from 1973 until 2006. Processing techniques have been developed, following standards from institutions and organizations of Strong Motion Seismology, after performing extensive tests, leading to a Matlab-based software under the name Proschema (Segou et al, 2008, under publication).

Spacing errors were found to be quite common in Volume 1 format files as well as misplaced values providing critical earthquake metadata. Through computer code utilization useful parameters have been stored in the form of metadata tables and a more flexible format has been chosen.

To address the inhomogeneity of the database each component was processed individually since digital and analogue recordings suffer from different sources of error. It is noted that, in order to maintain internal consistency, the horizontal components have been processed with the same specifications.

The first step of processing involved the derivation of a quality factor assigned to each record. The identification of rectangular pulses and clipping problems in the majority of analogue recordings refrain us from using further the records above in seismic hazard studies, due to their deficiency to produce credible spectral ordinates or even, in some cases, peak parameter values (Fig.1). Although the Fourier Amplitude Spectrum provides an excellent representation of the frequency content of a record, similar errors, as the aforementioned, can be detected only through the visual inspection of the uncorrected waveform. The evaluation of the quality of analogue records and their meticulous processing made possible to retain a great number of old but useful, recordings in the current database in an improved condition.

Secondly there has been a trivial need of generating equally sampled time series in a significant number of analogue recordings, in order to solve this problem new strong motion records equally sampled were created with step equal to the minimum digitization time interval of the original time series of the V1 format, as disseminated by the provider.

A common sampling rate at 200 samples per second was set from the beginning of the database's development which equals the sampling rate of the digital recordings whereas in analogue recordings the above rate was met after performing oversampling and decimation techniques, improving the overall quality of the latter. In order to prevent pseudo-aliasing phenomena a low pass filter was used when decimation is performed (Karl, 1989, Sherbaum 1996).

Instrument correction has been performed for analogue recordings, since the digital ones have flat response over a wide frequency range, by a second order differential equation which can adjust for the instrument response for frequencies reaching up to ¼ of the Nyquist frequency (Boore and Bommer, 2005); a frequency which is close to the nominal natural frequency of most operating analogue instruments.

The most critical step of any processing scheme lies in filtering of the time series in order to identify and remove the noise contamination and reproduce the actual ground motion.

Filter specifications correspond to a band pass 2p4p (2 pass 4 pole) infinite impulse response filter of Butterworth type implemented in the frequency domain. Acausal implementation is directly connected with bi-directional filtering after padding the original time series. Following comments found in Boore (2005) padding with appropriate number of samples (zero samples in our case) preceded acausal implementation to make allowance for the filter's impulse response.

Especially for the digital A-800 accelerometer of Teledyne-Geotech caution is advised when choosing the low cut off frequency, since its datalogger already includes a 0.1 Hz low cut filter. For the reason above when processing these records either no additional low cut filtering should be performed or the chosen cut off frequency should provide a usable data bandwidth inside the one defined from the previous hardware filtering. In any case, the hardware filtering didn't provide good quality velocity and displacement time series, and the need for choosing a higher frequency was pronounced. It is our belief that in most cases this hardware filtering deteriorates rather than improves the original time series.

Especially for choosing the suitable low cut off frequency, an additional step of visual inspection of acceleration, velocity and displacement time series corresponding to an acausal implementation of five filters with different user-defined cut off's, has been added.

It should be noted that the zero pads are retained throughout the integration for the velocity and displacement time series as well as for calculating Fourier Amplitude spectrum of the corrected acceleration time series and response spectra.

In any processing stage the authors refrain from performing further baseline adjustments since there is no real evidence of the affected frequency band after applying this correction. It is the authors' belief that no additional action, except filtering, for removing long period noise should be performed because this would represent the implementation of a second filter of unknown cut off frequency (Boore & Bommer, 2005).

The final major processing step involves the computation of the response spectra of the corrected acceleration time series with final products being the pseudo acceleration, the pseudo velocity and pseudo displacement for 0, 2, 5, 10 and 20 percent value of the critical damping and for a set of 159 period estimators ranging between 0.01s and 10s.

Since commonly used response measures in strong ground motion prediction equations, depend on the orientation of the sensors as installed in the field, the calculation of the two new measures of geometrical mean GMRotDpp and GMRotIpp, independent of the sensor orientations, as defined in Boore et al. (2006), can be helpful for seismic hazard studies and engineering practice. The calculation of these orientation independent measures is based on a set of geometric means computed from the as-recorded orthogonal horizontal motions rotated through all possible non-redundant rotation angles.

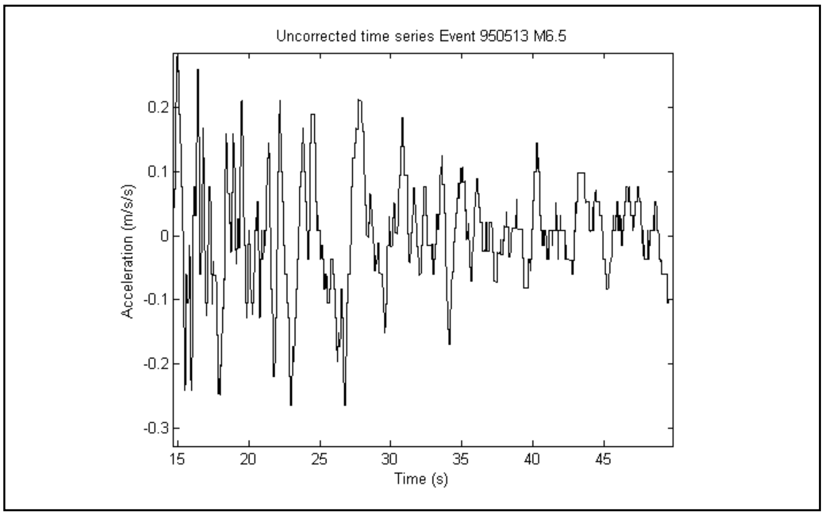

Figure 1. Poor quality strong motion record, not included in the GReD.

Results and Discussion

It is the authors' belief that the processing scheme described previously incorporates basic needs together with advanced techniques, combining principles of digital signal processing and main seismological practice.

The design of stable infinite impulse response filters, now available through the Matlab platform, contributes in preserving the actual frequency content of each recording and provides a well defined usable data bandwidth. It should be also noted that performing major corrections, as instrument and baseline adjustment, is within Proschema capabilities, but a detailed appreciation of the effects of each one on the frequency content of the recording preceded their final implementation.

The GReD consists of more than 250 carefully selected three-component strong motion records according to Volume 1, Volume 2 and Volume 3 format specifications. An additional Volume has been created to incorporate the new spectral measure GMRotI50 (Fig.2) in terms of pseudo acceleration, pseudo velocity and pseudo displacement for 5 percent value of the critical damping. The maximum response spectral ordinate in a single direction (Watson-Lamprey & Boore, 2007), which is found to be useful in some engineering applications, is also available. Although earthquake engineers are often provided with already processed data by engineering seismologists, the first should be able to understand that there is no such thing as corrected values and that spectral ordinates can be subjective, within limits, whereas the second should be able to understand the reason for this subjectivity as well as the influence of their processing approach on the disseminated data. The last two spectral ground measures are proposed for further use in both, seismic hazard studies and engineering practice, so that their contribution would be assessed and lead to a development of common ground between engineering seismologists and engineers.

The secondary purpose of this paper is to draw attention to the importance of choosing the appropriate processing scheme, bearing in mind the needs of the individual researcher, and to point out the sensitivity of spectral ordinates to different processing schemes. For this reason the GReD is provided diversified; the first version corresponds to an database of educational use after processing with pre-specified parameters affecting all strong motion recordings whereas the second version supports elaborate component-by-component processing which addresses each recording's needs and deficiencies. In both cases a suggested usable data bandwidth is clearly stated according to the filter's specifications.

Each strong motion recording is found in a number of formats; either as a binary file, as both a joint couple of binary .mat files containing strong motion data and a processing log for further Matlab use and in SAC format or as an ascii file according to smc format specifications or the format specifications of European Strong Motion Database. It should be also noted that Proschema supports the visualization of the time series in terms on waveforms or Fourrier and response spectra. It is also possible to convert between the aforementioned formats through the utilities of the software.

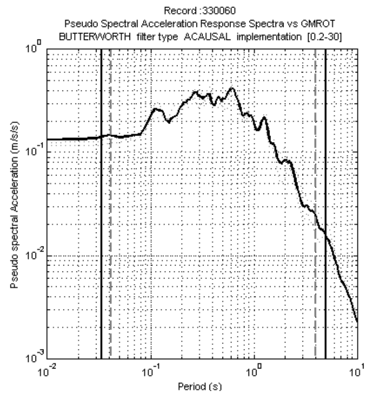

Figure 2. Orientation independent spectral acceleration response spectrum versus standard acceleration response spectra of the horizontal components for 5 percent value of the critical damping.

In the future the growing number of digital recordings is expected to improve the quality of the Greek database, but it is the authors' belief that the combination of both, better quality records and changes in standard processing of the existing strong motion records are necessary for further development of the database. For deriving credible spectral ordinates for period estimators greater than 3s digital recordings are necessary. A significant number of such operating instruments located near well known seismic sources could facilitate the study of hanging wall and directivity effects; improving seismic hazard assessment in the near field.

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