The Italian Accelerometric Archive (ITACA): processing of strong-motion data

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Abstract

The Italian strong-motion data base was created during a joint project between Istituto Nazionale di Geofisica e Vulcanologia (INGV, *Italian Institute for Geophysics and Vulcanology*) and Dipartimento della Protezione Civile (DPC, *Italian Civil Protection*).

The aim of the project was the collection, homogenization and distribution of strong motion data acquired in Italy in the period 1972-2004 by different institutions, namely Ente Nazionale per l'Energia Elettrica (ENEL, *Italian electricity company*), Ente per le Nuove tecnologie, l'Energia e l'Ambiente (ENEA, *Italian energy and environment organization*) and DPC. The data base contains 2182 waveforms from analog and digital instruments, generated by 1004 earthquakes with magnitude up to 6.9 and can be accessed on-line at the web site http://itaca.mi.ingv.it.

The strong motion data are provided in the unprocessed and processed versions. This article describes the steps followed to process the acceleration time series recorded by analogue and digital instruments. The procedures implemented involve: baseline removal, instrumental correction, band pass filtering with acausal filters, integration of the corrected acceleration in order to obtain velocity and displacement waveforms, computation of acceleration response spectra and strong motion parameters. This scheme, applied to each single accelerogram, is finalised to preserve the low frequency content of the records.

Keywords: strong-motion data, data processing, filtering, strong-motion parameters

1. INTRODUCTION

Italy is a country with a high seismicity rate, characterized by frequent low energy events and few moderate and energetic earthquakes. The availability of strong motion data, recorded from accelerometric networks, is fundamental for any study and application concerning earthquake engineering and engineering seismology. The strong motion databases represent a reference tool for professionals and researchers who deal with issues connected to seismic hazard.

ITACA (ITalian ACelerometric Archive) is the new Italian strong motion database, developed within the project *Data base dei dati accelerometrici italiani relativi al periodo 1972-2004* (Italian strong motion data base in the period 1972-2004) in the framework of the 2004-2006 DPC-INGV agreement. A fundamental task of the project was to establish a set of procedures for data processing and calculation of strong-motion parameters in order to provide end users with the corrected waveforms. ITACA at present contains 2182 waveforms generated by 1008 earthquakes with a maximum moment magnitude of 6.9 (1980 Irpinia earthquake), recorded both by analogue and digital recording systems. The strong motion data are provided in the unprocessed and processed version together with acceleration response spectra and strong motion parameters. This paper describes in detail the data processing procedures, from the raw to the processed data, illustrating the steps that led to the corrected version.

Before introducing the processing procedures, it is worth mentioning that the quality of the recordings included in ITACA reflects the technological progress of the strong-motion networks. Before 1997 the waveforms were almost totally recorded by analogue instruments (mainly Kinemetrics SMA-1), that worked with a trigger threshold, usually set on high peak ground acceleration values (usually 0.01g). The number of recordings is therefore quite limited (about 500). In this period the magnitude-range of the recorded events is 3–6.9 and includes the strongest Italian earthquakes. The analogue time-series were recorded on films, and this caused inconveniences such as the absence of the event date and time, which often prevents to associate the waveform to a seismic event, or the absence of the P-wave phase in the record, very often triggered by the S-phase.

The transformation in digital format occurred after digitalization of the film, which can be more or less accurate, depending on automatic or manual procedures. The records are extremely noisy, especially at low frequencies, because of the film sliding during the recording phase and the digitalization procedure. The high frequency content of the records is limited to the sensor frequency, which is usually 25 Hz, or lower (e.g. 12 Hz). Figure 1a shows as example the north-south component of the raw analogue acceleration time-series recorded at *Conegliano Veneto*, on 1976-05-06 at 20:00:12 GMT (Mw=6.5 Friuli main-shock) by a Kinemetrics SMA-1 accelerograph, with natural frequency of 22 Hz. The record shows an evident low frequency noise, while the P phase is completely absent.

Nevertheless, analogue data are still relevant, since the largest Italian earthquakes (Mw 6.5, 1976 Friuli earthquake; Mw 6.9, 1980 Irpinia earthquake; Mw 6.0, 1997 Umbria-Marche earthquake) were recorded by analogue instruments.

From 1997 to 2004 the number of records became three times larger (about 1700), because of the presence of high-dynamic digital instruments, which allowed to record low magnitude earthquakes, down to Ml 1. The maximum magnitude recorded in this period is Mw 6.0 and corresponds to the 1997-09-26, 9:40 GMT, Umbria-Marche mainshock. Digital recordings have the advantage of being directly available in digital format and the instruments are set in a way that, when a certain threshold is exceeded, the pre-event trace can be recovered and included in the record. Therefore information on the noise preceding the event are always available. If compared to analogue records, digital accelerograms are less noisy at low frequencies, while the high-frequency content is reliable up to 50 Hz or more, due to digitalization frequencies that usually exceed 100 Hz. Figure 1b shows as example the north-south component of the raw acceleration time-series recorded at *Chieti*, on 2002-11-12 at 09:27:48 (Mw=4.6) by a digital instrument equipped with Kinemetrics-Episensor FBA-3 sensor: in this case both P and S-phases are well reproduced and low frequancy noise is not evident.

Comment: See comment 1

In general, strong motion records, especially those recorded by analogue instruments, contain a certain level of noise than can mask and distort the ground-motion signal both at high and at low frequencies. For this reason, to provide usable recordings for engineering application, the level of noise contained in the data and its effect on the strong-motion parameters should be estimated and, in some way, “removed”.

In the last decades many papers concerning the treatment of strong-motion data were produced (e.g. Graizer, 1979; Basili, 1987; Rovelli, 1987; Rinaldis, 2005; Boore, 2001; Boore et al., 2002; Boore and Akkar, 2003; Boore and Bommer, 2005), with the conclusion that there is no unique standard for strong motion data processing and a certain degree of subjectivity, especially during the analogue data processing, is inevitable.

The procedures used in ITACA involve: mean removal, baseline correction, instrumental convolution, band pass filtering (with acausal filters) and integration of the processed acceleration in order to obtain velocity and displacement waveforms. In addition, acceleration response spectra and the main strong-motion parameters are calculated. This scheme is applied to individual records, with the aim of preserving the low frequency content of the signals.

3. DATA PROCESSING

As previously discussed, reliable estimates of acceleration, velocity and displacement time-series and acceleration response spectra can be obtained after an adequate processing.

As the Italian strong motion database contains both analogue and digital data, two different processing procedures were adopted after a common pre-processing, as resumed in the flow chart in figure 2.

3.1 FROM RAW DATA TO UNCORRECTED DATA

The data included in ITACA were pre-processed in order to remove the so called non-standard errors. Non-standard errors mean the presence of multiple events in the same records and presence of spikes. In the first case the time-series is split into multiple windows corresponding to single events, while, in the case of spikes, the anomalous value is replaced by values of contiguous samples. The spikes elimination, even if appears to led to slight modifications in the spectrum at long periods, represents a fundamental step because of spikes, being a broadband, constituted a serious contamination also at short period. As suggested by Boore and Bommer (2005) the derivate of acceleration, named “jerk”, it can be able to easier identify the spikes due to the conversion of a single spike into a double-side pulse.

For digital waveforms, in the case of low dynamic digitizers (i.e. 12 bits), the ratio between the peak ground acceleration and the minimum recordable value is calculated, in order to discard records having a ratio lower than 20.

The analogue data are provided with the corresponding fixed trace, that represents the film sliding during recording; not used for data processing. Most of the analogue data, were digitized with constant sampling rate of 0.00244 s, but many data are only available after manual-digitizing and are unevenly spaced. All the uncorrected data were re-sampled to 200 point/s (dt = 0.005 s).

The result of the pre-processing are the uncorrected-data. This term indicates that the digitized or digitally recorded time series have undergone no processing.

Comment: See comment 3

3.2 PROCESSED DATA

To obtain the processed data several steps (fig. 2) were performed, which are illustrated in the following paragraphs:

3.2.1 Step 1: baseline correction

A first-order baseline operator is applied to the entire record, in order to have a zero-mean of the signal, then, a simple baseline correction is applied by removing the linear trend, computed with a least square method. Figure 3 shows as example the NS-component recorded at Nocera Umbra on 26th September 1997 (09:40 UTM), during the Mw 6.0 Umbria-Marche main-shock, before and after the baseline correction: in figure both acceleration and velocity (obtained after integration) time-series are reported. As showed in the example of figure 3, baseline offsets were generally very small therefore it was not necessary to apply more complex corrections, such as piecewise fitting of linear or higher order polynomials (Boore 2001; Boore et al., 2002; Iwan et al., 1985). After baseline correction low frequency noise could be still present, which can be removed after long period filtering. When the displacement trace is used to recover the permanent displacement baseline adjustments can be more convenient than high-pass filtering and a specific processing should be applied to the uncorrected data (Boore and Bommer, 2005), but this task is beyond the aim of this project.

3.2.2 Step 2: instrument convolution

This step is only applied to analogue data after baseline removal. Analogue instruments are mostly Kinemetrics SMA-1 or Teledyne RFT-250, with natural frequency in the range 12–25 Hz.

The data are corrected in the frequency domain for the instrument response whose characteristics are included in the file header where damping and natural frequency are specified. The convolution with the instrument response could generate unrealistic high-frequency motions due to the amplification of the high-frequency noise introduced by the digitization process. For this reason a low-pass filter should be successively applied.

Comment: See comment 4

Figures 4a and 4b show the NS-component recorded at Nocera Umbra on 26th September 1997, during the Mw 6.0 Umbria-Marche main-shock, before and after the instrumental correction. It can be noticed that, after the instrument correction, the peak horizontal acceleration of the analogue record increases from 550 cm/s^2 (the value obtained from the uncorrected data after baseline removal) up to 1048 cm/s^2. In order to avoid these biases a careful selection of a low-pass filter will be necessary. It is worth noting that, the instrument corrections is not necessary for digital records (Boore and Bommer; 2005), since the instrumental response is usually flat up to 50 Hz.

3.3.3 Step 3: Band-pass filtering

Digital data, after baseline removal, and analogue data, after baseline removal and instrument convolution, are band-pass filtered in order to remove the high and low-frequency noise. Generally, acausal filters are preferred since they do not produce a phase distortion in the signal. Different studies show, in fact, that causal filters may influence the displacement waveforms and elastic and anelastic response spectra (Boore and Bommer, 2005). In particular, causal filters can affect spectral ordinates at frequencies higher than the applied low cut frequency (Boore and Akkar, 2003). Digital data were filtered using an acausal 4th order Butterworth filter. When acausal filters are applied, data should be padded with zero's in order to accommodate the filter transient.

Comment: See comment 6

In this application the zero's were added applying a cosine taper at both sides of the record. The impossibility of padding the greatest part of analogue strong motion data, usually triggered on the S arrival, led to use a raised cosine filter. In ITACA, the corrected accelerations are provided with the added zero's in order to be compatible with the corrected velocity and displacement record. The selection of the optimal low and high-cut frequencies are the most critical steps of data processing, especially for analogue data

In order to illustrate the problems related to the low-pass filtering, we select the NS acceleration components of the same event (6^{th} October 1997, Mw = 5.4) recorded at the same site by a digital (NCR2) and an analogue (NCR) instrument (fig. 5). The uncorrected peak ground accelerations of the digital and the analogue instruments are 531 cm/s^2 and 516 cm/s^2, respectively (Figures 5a and 5b). The different values depend on the different instrument responses, the former being characterized by a natural frequency of 50 Hz, the latter by 19 Hz. The uncorrected digital PGA value could be therefore considered very close to the actual ground motion acceleration. The comparison between the acceleration Fourier spectra from analogue and digital data highlight how the noise affects the signals at low and high-frequencies in different way (Figure 5c).

Comment: See comment 5

Following the Itaca standard processing, after baseline removal, the analogue record was corrected for the instrumental response. The comparison between the Fourier spectra of the digital record, after baseline removal, and the analogue record, after instrument convolution, is shown in Figure 5d: the increase in high frequency content in the spectrum of the analogue record is evident. In the time domain the PGA increases from 516 cm/s^2 to 648 cm/ s^2 (Figure 5e). A low-pass filter was applied to the analogue accelerogram convolved with the instrumental response, with low-pass frequencies equal to 30 and 20 Hz with corresponding peak ground accelerations of 515 cm/s^2 (Figure 5f) and 476 cm/s^2 (Figure 5g). A PGA of 515 cm/s^2 is very close to the value obtained from the corrected digital waveform, finally band-pass filtered between 0.25 and 30 Hz (514 cm/s^2), as shown in Figure 5h.

However, the case of NCR station is unique: all the rest of the analogue data have no corresponding digital waveforms recorded at the same site.

To avoid the biases introduced by the convolution for instrumental response, in ITACA processing the low-pass filter for analogue data is chosen taking into account the instrument frequency.

For digital data the choice of the low-pass filter was made on the basis of the visual inspection of the Fourier amplitude spectra: the general criterion was to select low-pass values where each spectrum deviates, in high frequency, from a linear decay. For a great amount of data this value was found in correspondence of about 30 Hz. In all cases different high-cut frequency values were tested in order to check their influence on the peak ground acceleration.

Moreover, since a high number of the analysed stations are installed in correspondence of little-plants for electric-power, the low-pass value represents a compromise between the possibility to lose some frequencies of the signals (however not meaningful for engineering issues) but taking into account the need of avoid the contamination of antropic spurious high-frequency spikes (i.e. 50 Hz is a typical frequency of the electric-energy).

The intrinsic noise level due to the digitization and processing steps, as well as instrumental instabilities, heavily influence long periods, causing drifting in the velocity and displacement traces computed by integrating the acceleration time series. The long period noise is present in both analogue and digital recordings, though it is generally higher for optically digitized data than for digital ones (see Fourier spectra in fig. 5c).

The selection of the optimal high-pass frequency is very critical in the processing procedure since no-objective criteria can be adopted: its choice represents the most important issue in processing strong-motion accelerograms. Different approaches can be used, such as the comparison between the Fourier amplitude spectrum of the record with that of a model of the noise (obtained from pre-event memory for digital records and from fixed trace for analogue records) (Trifunac, 1977; Shakal and Radsdale, 1984; Boore and Bommer, 2005), or judging where the long period portion of the Fourier spectrum of the record deviates from the tendency to decay in proportion to the reciprocal of the frequency squared (at low frequancies the Fourier spectrum of acceleration decays according to f^2) (Basili and Brady, 1978; Boore and Bommer, 2005), or judging, from a physical point of view, the reliability both of the velocity and displacement time-series obtained by double integration.

In ITACA, the high pass frequency is chosen observing the deviation from an omega-square source model of the Fourier acceleration spectrum and verifying the displacement waveforms obtained by double integration of the filtered acceleration traces. This step was performed individually for each component.

In the example of fig. 6 (analogue waveform recorded at Nocera Umbra on 26th September 1997) the long period corner frequency was set equal to 0.5 Hz, as, at frequencies lower than 0.5 Hz, the recorded spectrum displays an evident deviation from an omega-square shape. The band-pass filtered acceleration time series obtained after the processing is reported in fig. 7: the obtained PGA is 473 cm/s^2. In this case, the noise affecting the analogue record (NCR) both at low and high frequency not allow to select a wide band pass filter like that applied to the corresponding digital record (0.25-30 Hz, see NCR2 in figure 5h). The final result, in terms of PGA, is that the analogue station of Nocera Umbra slight underestimates the maximum peak ground acceleration (473 cm/s^2 Vs. 514 cm/s^2).

3.3.4 Step 4: Computation of response spectra and strong motion parameters

For both analogue and digital processed accelerograms, velocity and displacement time series were computed by integration (fig. 7). Velocity time series are directly obtained by trapezoidal integration of the acceleration time series, while displacement time series are obtained by integrating the velocity waveforms after linear trend removal. The processed accelerograms, together with velocity and displacements traces, are archived including the zeros artificially added for the acausal filter application in order to ensure compatibility among corrected acceleration time series and the derived parameters.

The 5% damped acceleration response spectra are computed for 25 periods, spanning from 0.03 s up to 10 s using the method by Nigam and Jennings (1968). Each response spectrum is calculated in the usable bandwidth, defined by the band-pass range. Moreover, the most common strong motion parameters are computed (Table 1) and stored in the database, such as the peak ground acceleration (PGA, in cm/s^2), the peak ground velocity (PGV, in cm/s) and the peak ground displacement (PGD, in cm). The effective peak acceleration (EPA, Algermissen and Perkins, 1976) is obtained considering the average of the acceleration response spectrum ordinates in the range 0.1 s - 0.5 s, divided for a factor of 2.5. Integral parameters and duration parameters were also calculated, such as the Arias Intensity (IA, Arias, 1970) and the Trifunac duration T90 (Trifunac and Brady, 1975).

Table 1 Strong motion parameters computed from processed accelerograms

Parameter	**Definition**
Peak ground acceleration (PGA in cm/s^2)	$\mathrm{PGA} = \max \lvert a(t) \rvert$
Peak ground velocity (PGV in cm/s)	$\mathrm{PGV} = \max \lvert v(t) \rvert$
Peak ground displacement (PGD in cm)	$\mathrm{PGD} = \max \lvert d(t) \rvert$
Arias Intensity (Ia in cm/s)	$I_a = \frac{\pi}{2g} \int [a(t)]^2 \, dt$
Effective peak acceleration (Epa in cm/s^2)	$EPA = \frac{average[SA(0.1,0.5)]}{2.5}$
Trifunac duration T_{90} (in s)	Time corresponding to the 90% energy release

4. CONCLUSIONS

A robust data processing procedure, for analogue and digital data, is essential to ensure high quality accelerograms of immediate use for engineering application and seismological studies. The paper describes the data processing adopted to correct the strong-motion data contained in the ITalian ACcelerometric Archive (ITACA) and illustarted in figure 2. Automatic procedures were rejected since they may introduce bias in the corrected waveforms or cause information loss, especially at longer periods. Each waveform was individually processed that also implies an individual pre-processing, since a visual inspection of the raw recordings was necessary to eliminate spurious spikes or multiple events. Analogue and digital data were processed with different procedures, with particular care in the treatment of analogue data, as the strongest Italian events were recorded by analogue instruments. In addition, post-processing data verification was executed, through the visualization of displacement waveforms or Fourier spectral shapes.

In conclusion, although there is no unique procedure for strong-motion data processing, the ITACA waveforms were treated following worldwide accepted techniques aimed to remove low and high frequency noise in order to reliable estimations of velocity and displacement time-series.

Being aware that, whatever the processing adopted, a certain degree of subjectivity is always introduced, the ASCII file header of the processed waveforms contains the necessary processing metadata to provide the end user with the tools for a correct data use. For specific engineering application or seismological studies, which could require different data processing, the uncorrected waveforms are also stored in the database and accessible to skilful users.

REFERENCES

Algermissen ST, Perkins DM (1976) A probabilistic estimate of maximum acceleration in rock in the contiguous United States. U.S. Geological Survey Open-File Report OF 76-416, pp 45.

Arias A (1970) A measure of earthquake intensity. In: Seismic Design of Nuclear Power Plants, Hansen R (ed), M.I.T. press, Cambridge.

Basili M, Brady AG (1978) Low frequency filtering and the selection of limits for accelerogram corrections. In: Proc. Sixt European on Earthq. Engineering, Yugoslavia.

Basili M (1987) Data acquisition and processing in strong motion seismology. In: Strong Ground motion seismology Erdik MO Toksoz MN (eds.), Reidel D Publishing Company, pp 251-331,.

Boore DM (2001) Effect of the baseline correction on displacements and response spectra for several recordings of the 1999 Chi-Chi, Taiwan, earthquake. Bull. Seism. Soc. Am. 91: 1199-1211.

Boore DM, Stephens CD, Joyner WB (2002) Comments on baseline correction of digital strong motion data: example from the 1999 Hector Mine, California, earthquake. Bull. Seism. Soc. Am**.** 92. 1543-1560.

Boore DM, Akkar S (2003) Effect of casual and acasual filters on elastic and inelastic spectra. Earthquake Eng. Struct. Dyn. 32: 1729-1748.

Boore DM, Bommer JJ (2005) Processing of strong-motion accelerograms: needs, options and consequences. Soil Dynamics and Earthquake Engineering 25: 93-115.

Graizer VM (1979) Determination of the true ground motion displacement by using strong motion records. Izvestiya, Phys. Soil Earth 15: 875-885.

Iwan WD, Moser MA, Peng CY (1985) Some observation on strong motion earthquake measurements using digital accelerograph. Bull. Seism. Soc. Am. 75: 1225-1246.

Nigam NC, Jennings PC (1968) Digital calculation of response spectra from strong motion earthquake records. CALTECH, Report. Pasadena (CA).

Rinaldis D (2005) Acquisition and processing of analogue data and digital accelerometric records: ENEA methodology and experience from Italian earthquakes. URL: http://www.cosmos-eq.org/recordProcessingPapers.html/

Rovelli A (1987) Strong ground motion in Italy: accelerogram spectral properties and prediction of peak values. In: Strong Ground motion seismology, Erdik MO and Toksoz MN (eds), Reidel D Publishing Company, pp 333-354, .

Shakal AF, Ragsdale JT (1984) Acceleration, velocity and displacement noise analysis for the CSMIP accelerogram digitization system. In: Proc. 8th World Conf. Earthquake Engeenering 2, 111-118.

Trifunac MD, Brady AG (1975) A study of the duration of strong earthquake ground motion. Bull. Seism. Soc. Am. 65: 581-626.

Trifunac MD (1977) Uniformly processed strong earthquake ground acceleleration in western United States of America for the period from 1933 to 1971: pseudo relative velocity spectra and processing noise. Report CE 77-04, Univ. Souther Calif., Los Angeles.

CAPTIONS

Fig. 1 a) North-South component of the acceleration time-series recorded at Conegliano Veneto, 6th May 1976 at 20:00:12 GMT (Mw=6.5; epicentral distance R=91 km) by an analogue instrument equipped with Kinemetrics SMA-1 sensor.

b) North-South component of the acceleration time-series recorded at Chieti, on 12th November 2002 at 09:27:48 (Mw=4.6; epicentral distance R=94 km) by a digital instrument equipped with Kinemetrics-Episensor FBA-3 sensor.

Fig. 2 Flow chart showing the data processing adopted for the Italian strong-motion data base.

Fig. 3 Example of baseline correction for NS component recorded by the analogue station installed at Nocera Umbra (NCR, Umbria, Italy) during the 26th september 1997 (09:40 UTM), Mw 6.0, Umbria-Marche main-shock: uncorrected acceleration record (a), baseline corrected accelerogram (b), velocity obtained by integration (c). Peak ground values are also reported.

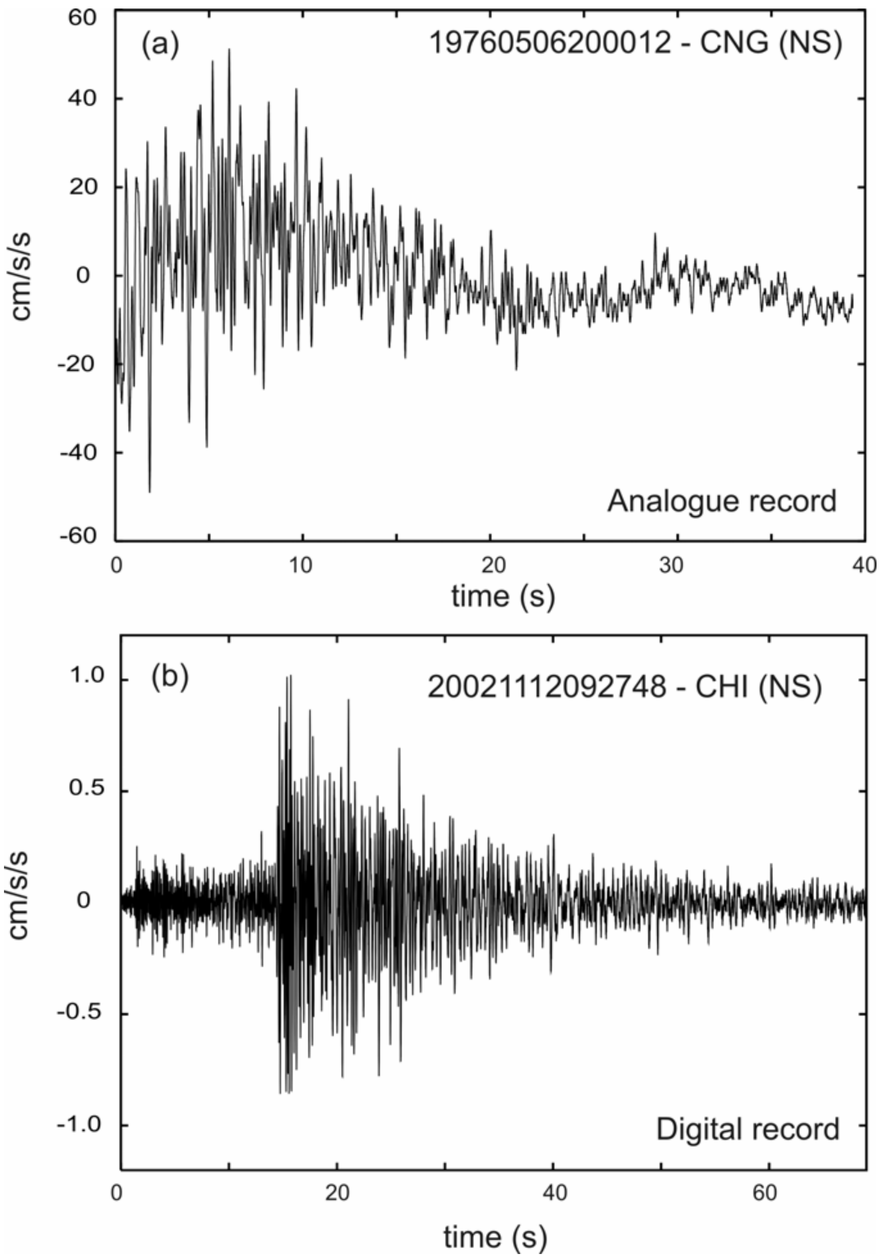
Fig. 4 a) Example of convolution with the instrument response for the time series showed in fig. 3. Top panel: acceleration time series after baseline removal; bottom panel: acceleration time series after baseline removal and instrumental convolution (SMA-1 accelerometer, with natural frequency of 19 Hz). The peak ground acceleration values are also reported. It is worth noting that this step could lead to a high frequency overestimation.

b) acceleration Fourier spectra calculated for time series of fig. 4a: the grey line is the spectrum after baseline removal while the black line is the spectrum after the convolution with the instrument response.

Fig. 5 Event recorded on 6th October 1997 (Mw 5.4) at Nocera Umbra: a) uncorrected digital time-series; b) uncorrected analogue time-series c) spectra of uncorrected analogue (grey line) and digital (black line) records; d) comparison between the Fourier spectrum of the digital record after baseline removal (black line) and the analogue record after baseline removal and instrument convolution (grey line); e) time series of the analogue data after instrument response removal; f) time series of the analogue data after instrument response removal and 30 Hz low-pass filter; g) time series of the analogue data after instrument response removal and 20 Hz low-pass filter; h) digital waveform filtered in the band-pass range 0.25-30 Hz.

Fig. 6 Example of band-pass filtering for the analogue signal recorded at Nocera Umbra on 26th September 1997. The high-pass frequency is set to 0.5 Hz, selected by visual inspection of the Fourier spectrum. The low-pass frequency is equal to 20 Hz, close to the natural frequency of the instrument (f_0 = 19 Hz).

Fig. 7 Example of processed data: north-south component of the 26th September 1997 Umbria-Marche earthquake (Mw 6.0), recorded by the analogue station of Nocera Umbra (NCR); from top to bottom acceleration, velocity and displacement time series.



(a)
19760506200012 - CNG (NS)
Analogue record
cm/s/s
time (s)
60
40
20
0
-20
-40
-60
0
10
20
30
40
(b)
20021112092748 - CHI (NS)
Digital record
cm/s/s
time (s)
1.0
0.5
0
-0.5
-1.0
0
20
40
60

Figure 1

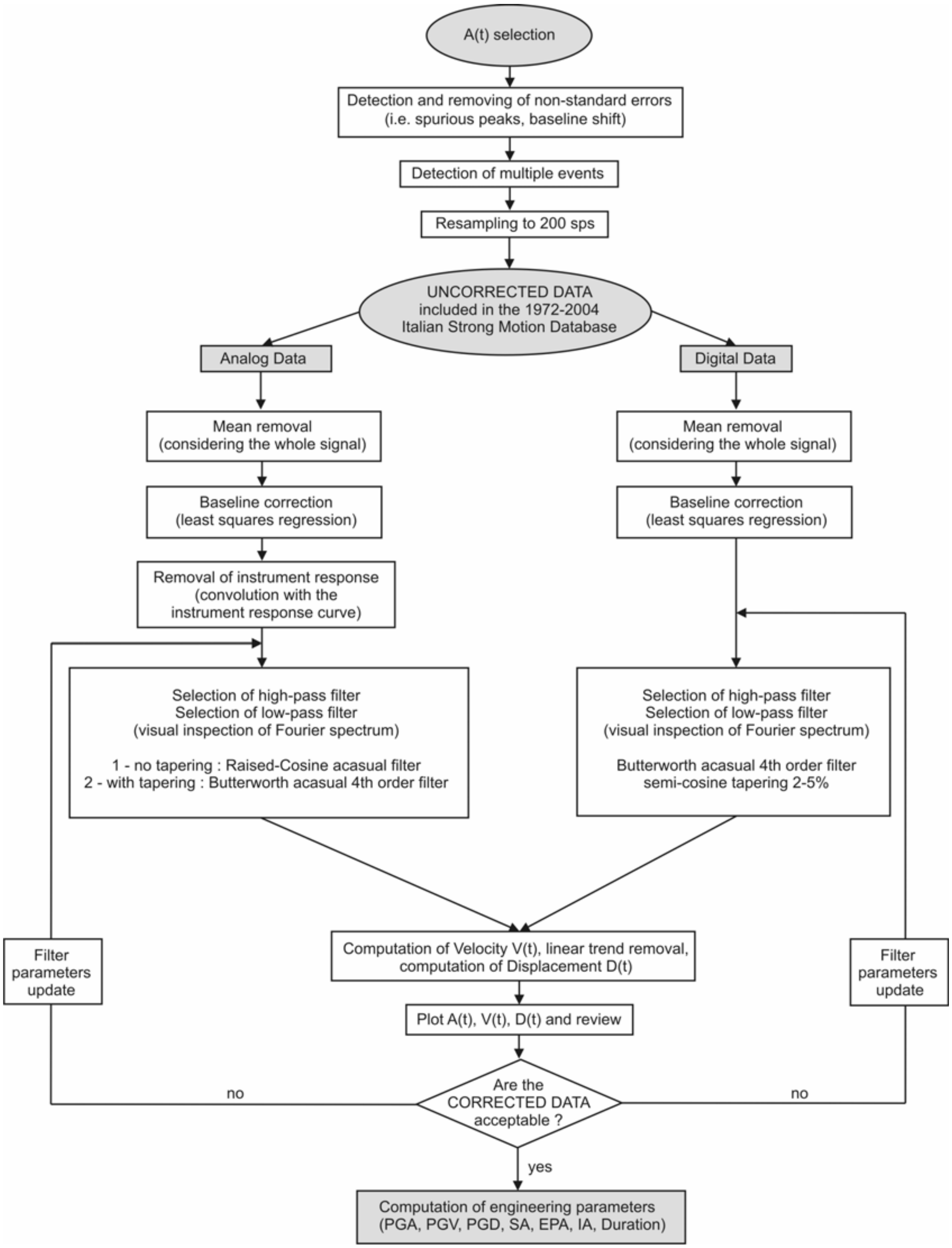

A(t) selection
Detection and removing of non-standard errors
(i.e. spurious peaks, baseline shift)
Detection of multiple events
Resampling to 200 sps
UNCORRECTED DATA
included in the 1972-2004
Italian Strong Motion Database
Analog Data
Digital Data
Mean removal
(considering the whole signal)
Baseline correction
(least squares regression)
Removal of instrument response
(convolution with the
instrument response curve)
Selection of high-pass filter
Selection of low-pass filter
(visual inspection of Fourier spectrum)
1 - no tapering : Raised-Cosine acasual filter
2 - with tapering : Butterworth acasual 4th order filter
Mean removal
(considering the whole signal)
Baseline correction
(least squares regression)
Selection of high-pass filter
Selection of low-pass filter
(visual inspection of Fourier spectrum)
Butterworth acasual 4th order filter
semi-cosine tapering 2-5%
Filter
parameters
update
Computation of Velocity V(t), linear trend removal,
computation of Displacement D(t)
Filter
parameters
update
Plot A(t), V(t), D(t) and review
no
Are the
CORRECTED DATA
acceptable ?
no
yes
Computation of engineering parameters
(PGA, PGV, PGD, SA, EPA, IA, Duration)

Figure 2

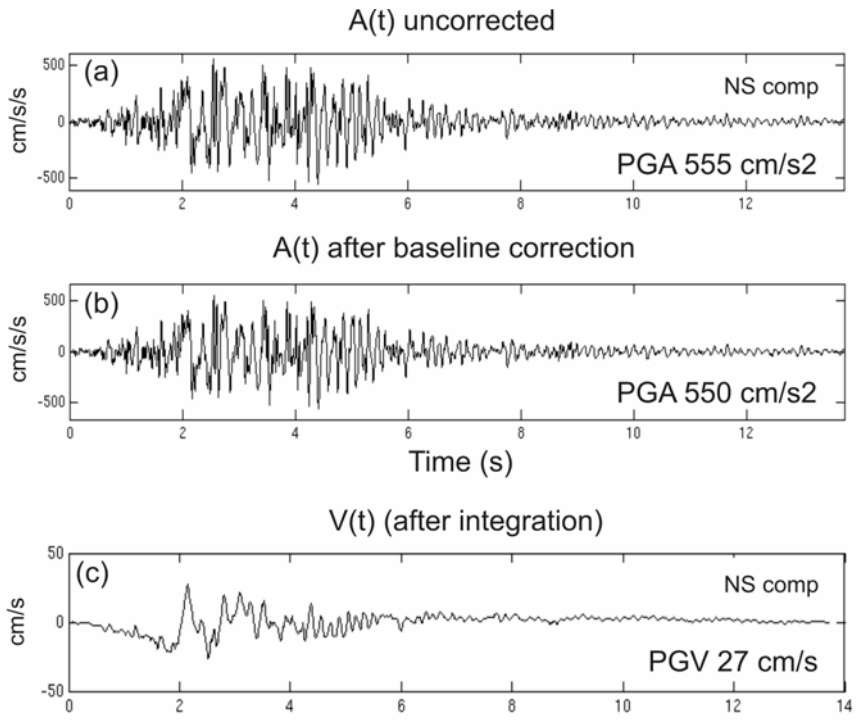
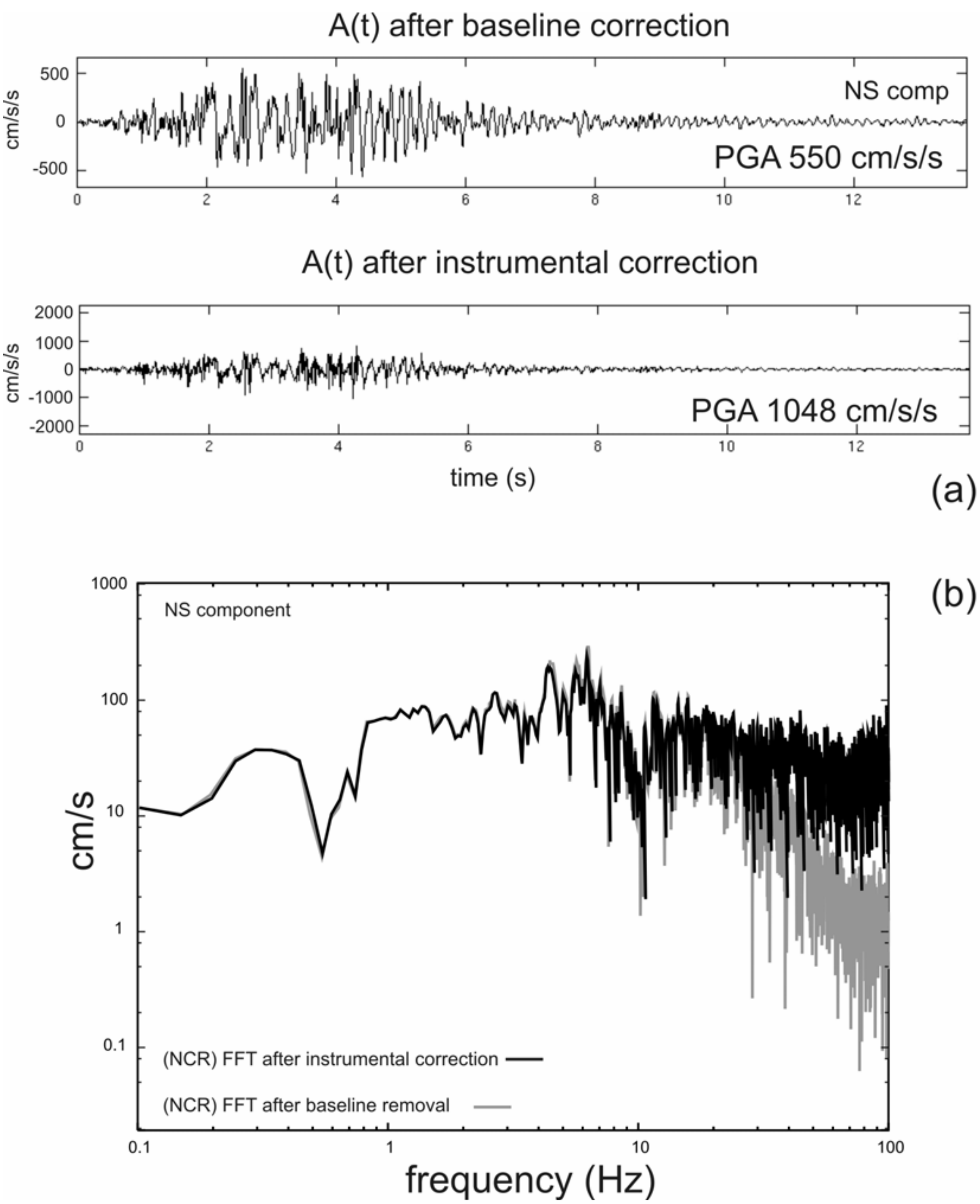

A(t) uncorrected
(a)
NS comp
PGA 555 cm/s2
cm/s/s
500
0
-500
0
2
4
6
8
10
12
A(t) after baseline correction
(b)
PGA 550 cm/s2
cm/s/s
500
0
-500
0
2
4
6
8
10
12
Time (s)
V(t) (after integration)
(c)
NS comp
PGV 27 cm/s
cm/s
50
0
-50
0
2
4
6
8
10
12
14

Figure 3



A(t) after baseline correction
NS comp
PGA 550 cm/s/s
cm/s/s
500
0
-500
0
2
4
6
8
10
12
A(t) after instrumental correction
PGA 1048 cm/s/s
cm/s/s
2000
1000
0
-1000
-2000
time (s)
(a)
(b)
NS component
cm/s
1000
100
10
1
0.1
(NCR) FFT after instrumental correction
(NCR) FFT after baseline removal
0.1
1
10
100
frequency (Hz)

Figure 4

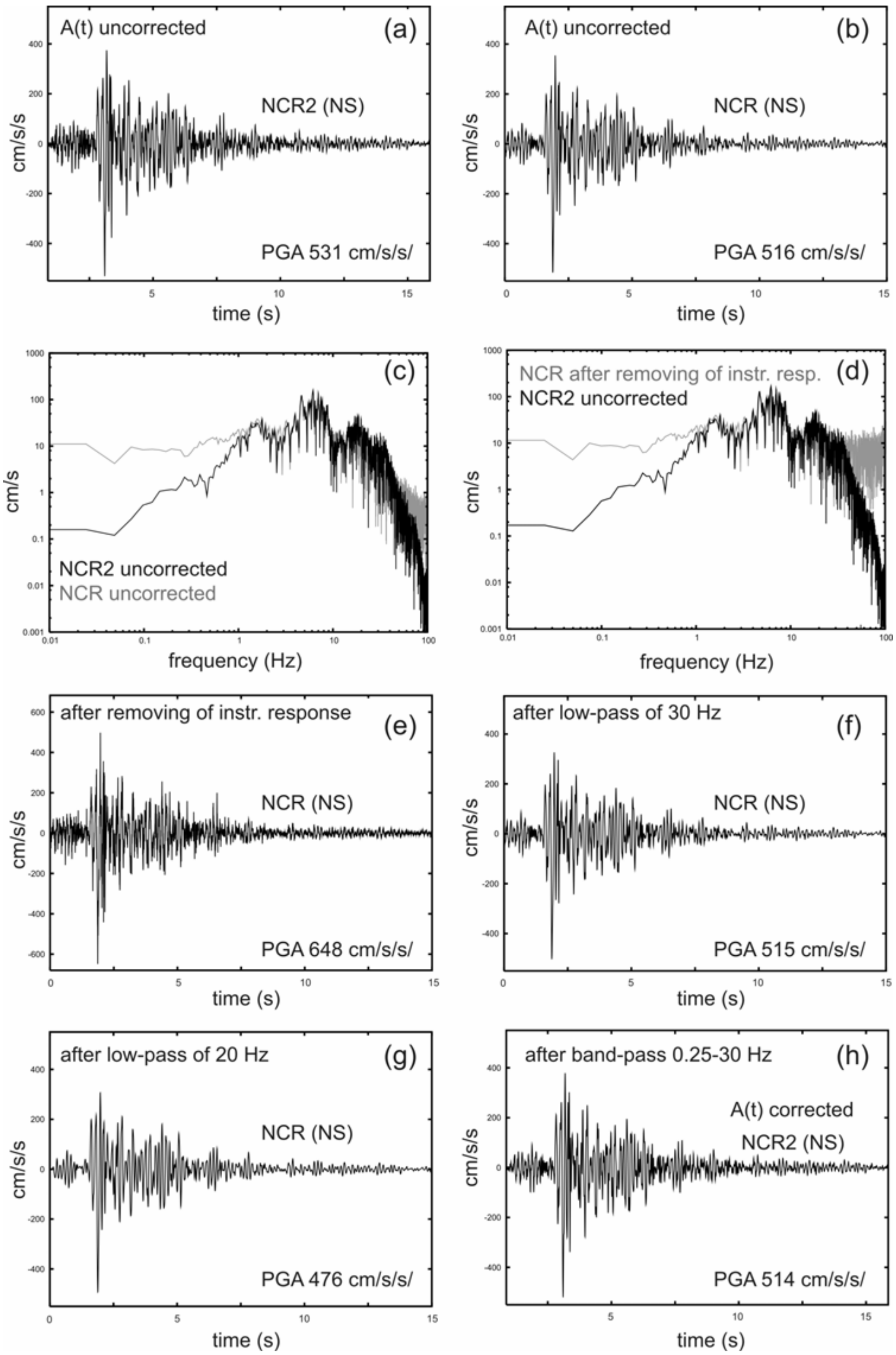

A(t) uncorrected
(a)
NCR2 (NS)
PGA 531 cm/s/s/
cm/s/s
time (s)
A(t) uncorrected
(b)
NCR (NS)
PGA 516 cm/s/s/
cm/s/s
time (s)
(c)
NCR2 uncorrected
NCR uncorrected
cm/s
frequency (Hz)
NCR after removing of instr. resp.
(d)
NCR2 uncorrected
cm/s
frequency (Hz)
after removing of instr. response
(e)
NCR (NS)
PGA 648 cm/s/s/
cm/s/s
time (s)
after low-pass of 30 Hz
(f)
NCR (NS)
PGA 515 cm/s/s/
cm/s/s
time (s)
after low-pass of 20 Hz
(g)
NCR (NS)
PGA 476 cm/s/s/
cm/s/s
time (s)
after band-pass 0.25-30 Hz
(h)
A(t) corrected
NCR2 (NS)
PGA 514 cm/s/s/
cm/s/s
time (s)

Figure 5

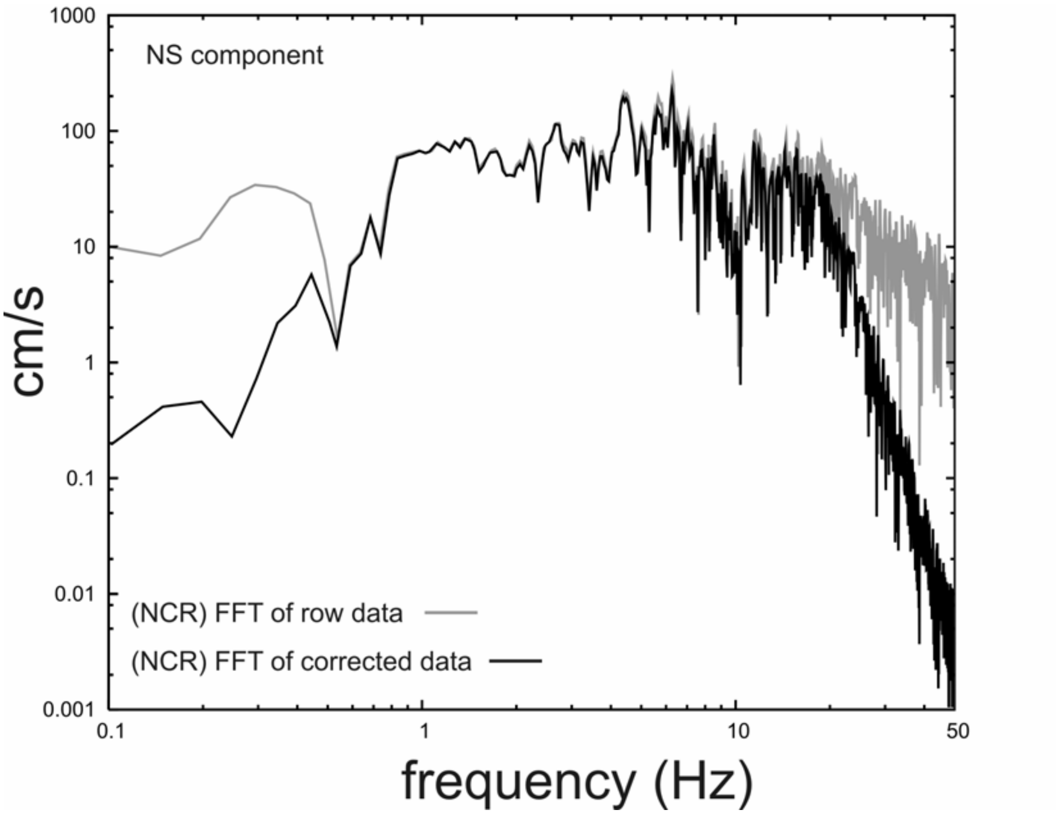
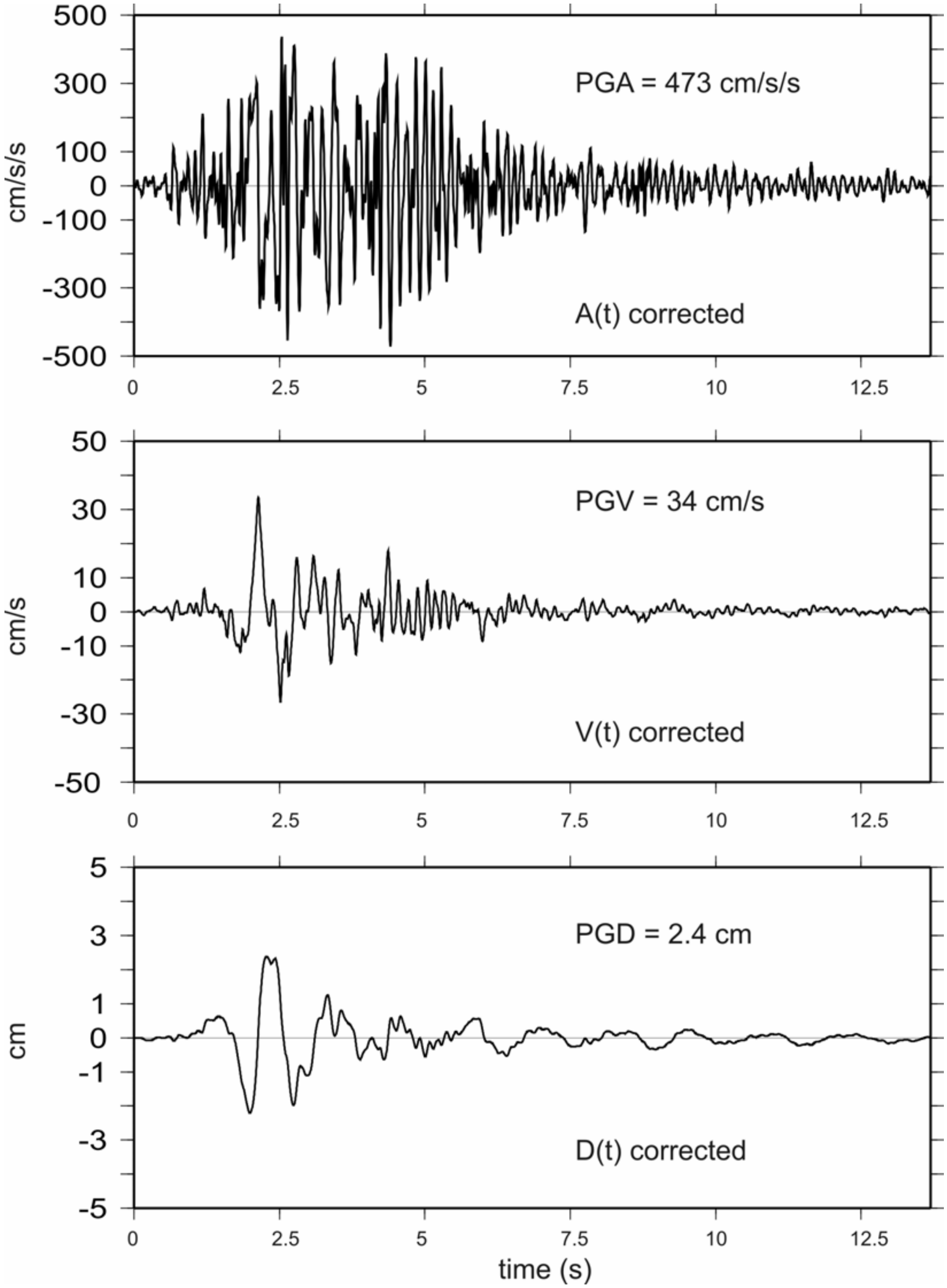

NS component
cm/s
1000
100
10
1
0.1
0.01
0.001
0.1
1
10
50
frequency (Hz)
(NCR) FFT of row data
(NCR) FFT of corrected data

Figure 6



500
300
100
0
-100
-300
-500
cm/s/s
PGA = 473 cm/s/s
A(t) corrected
0
2.5
5
7.5
10
12.5
50
30
10
0
-10
-30
-50
cm/s
PGV = 34 cm/s
V(t) corrected
5
3
1
0
-1
-3
-5
cm
PGD = 2.4 cm
D(t) corrected
time (s)

Figure 7