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Abstract

The development of the new Italian strong-motion database ITACA (ITalian AC-celerometric Archive, http://itaca.mi.ingv.it) is in progress under the sponsorship of the National Department of Civil Protection (DPC) within Project S4, in the framework of DPC-INGV 2007–2009 research agreement. This work started from the alpha version of ITACA [8], where 2,182 3-component records from 1,004 earthquakes, mainly recorded by the National Accelerometric Network, RAN, operated by DPC, were processed and included in the database. Earthquake metadata, recording station information and reports on the available geological-geophysical information of 452 recording sites, corresponding to about 70% of the total, were also included. Subsequently, ITACA has been updated and will reach its final stage by the end of Project S4, around mid-2010, with additional features, improved information about recording stations, and updated records, including the Mw6.3 L'Aquila earthquake. All records were re-processed with respect to the alpha version [9], with a special care to preserve information about late-triggered events and to ensure compatibility of corrected records, i.e., velocity and displacement traces obtained by the first and second integral of the corrected acceleration should not be affected by unrealistic trends. After a short introduction of ITACA and its most relevant features and statistics, this paper mainly deals with the newly adopted processing scheme, with reference to the problems encountered and the solutions that have been devised.

Chapter 8
Record Processing in ITACA, the New Italian Strong-Motion Database

AQ1

R. Paolucci, F. Pacor, R. Puglia, G. Ameri, C. Cauzzi, and M. Massa

Abstract The development of the new Italian strong-motion database ITACA (ITalian AC-celerometric Archive, http://itaca.mi.ingv.it) is in progress under the sponsorship of the National Department of Civil Protection (DPC) within Project S4, in the framework of DPC-INGV 2007–2009 research agreement. This work started from the alpha version of ITACA [8], where 2,182 3-component records from 1,004 earthquakes, mainly recorded by the National Accelerometric Network, RAN, operated by DPC, were processed and included in the database. Earthquake metadata, recording station information and reports on the available geological-geophysical information of 452 recording sites, corresponding to about 70% of the total, were also included. Subsequently, ITACA has been updated and will reach its final stage by the end of Project S4, around mid-2010, with additional features, improved information about recording stations, and updated records, including the Mw6.3 L'Aquila earthquake. All records were re-processed with respect to the alpha version [9], with a special care to preserve information about late-triggered events and to ensure compatibility of corrected records, i.e., velocity and displacement traces obtained by the first and second integral of the corrected acceleration should not be affected by unrealistic trends. After a short introduction of ITACA and its most relevant features and statistics, this paper mainly deals with the newly adopted processing scheme, with reference to the problems encountered and the solutions that have been devised.

8.1 Introduction

The development of the new Italian strong-motion database ITACA (ITalian ACcelerometric Archive, http://itaca.mi.ingv.it) is in progress under the sponsorship of the Italian Department of Civil Protection (DPC) within Project S4, in the framework of DPC-INGV 2007–2009 research agreement. This Project has

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continued the activity originally developed by Project S6, within the previous 2004–2006 DPC-INGV agreement, in which the alpha version of ITACA was originally developed [8].

The main goal of the S6 and S4 Projects has been to organize into a comprehensive, informative and reliable database (and related webtools) the wealth of strong-motion records, obtained in Italy during the seismic events occurred starting from the Ancona earthquake sequence in 1972, up to the L'Aquila 2009 sequence.

The beta version of ITACA, which will reach its final stage by the end of the project, around mid-2010, will include several improvements and additional features, namely: – strong motion records from other local and/or temporary networks, and from recent seismic events, in primis the April 6 2009 M_W6.3 L'Aquila earthquake and its main aftershocks; – updated reports, with an improved format, on the available geological/geophysical information of recording stations, including average HVSR from microtremors and earthquakes where available; – identification of stations and records showing distinctive features, either due to geological/topographic irregularities or due to seismic source effects; – online tools for selection of spectrum-compatible records.

To date, ITACA contains 2,550 three-component waveforms: 2,293 of them were recorded during 1,002 earthquakes with a maximum moment magnitude of 6.9 (1980 Irpinia earthquake) in the period range 1972–2004, while the rest comes from the M_W5.4 2008 Parma (Northern Italy) and from the M_W6.3 2009 L'Aquila (Central Italy) earthquakes and related $M_W > 4$ aftershocks. Records obtained in 2005–2007 will be included by the end of the Project.

The recordings mainly come from the National Accelerometric Network (RAN, Rete Accelerometrica Nazionale), now operated by DPC. RAN presently consists of 334 free-field digital stations and 84 analogue stations, the replacement of which with digital instruments is currently in progress. The goal is to achieve a final configuration of more than 500 digital stations installed throughout the Italian territory, with an average inter-station spatial distance of about 20–30 km in the most seismically active regions of Italy (A. Gorini, personal communication, 2010). Further records are provided by the Strong Motion Network of Northern Italy (*Rete Accelerometrica dell'Italia Settentrionale*, RAIS http://rais.mi.ingv.it, [2]), consisting of digital instruments, installed around the Garda lake area, and by sparse stations (analogue and digital) operated by ENEA (Ente per le Nuove tecnologie, l'Energia e l'Ambiente (*Italian energy and environment organization*)), over the time span 1972–2004. In addition to these, waveforms recorded during the L'Aquila seismic sequence by the accelerometer installed on the very broad band AQU station (http://mednet.rm.ingv.it) are also present.

All ITACA records were re-processed with respect to the alpha version [9], with a special care to preserve information about late-triggered events and to ensure compatibility of corrected records, i.e., velocity and displacement traces obtained by the first and second integral of the corrected acceleration should not be affected by unrealistic trends.

This paper mainly deals with the newly adopted processing scheme, with reference to the problems encountered and the solutions that have been devised.

8.2 Characteristics of the ITACA Dataset

Figures 8.1 and 8.2 summarize the main characteristics of the ITACA dataset in terms of focal parameters and distance ranges. As shown in Fig. 8.1, magnitude (either M_w or M_L) ranges from 2 to 6.9 with the best sampled distance interval from 5 to 100 km. The epicentral distance (R_{epi}), for M < 5.5 events, and the Joyner-Boore distance (R_{jb}) for stronger earthquakes are considered, based on the fault geometry data available in the DISS database [3, 6]. Nine 3-component records with epicentral distance $R_{epi} \leq 10$ km are available in the range $5.9 \leq M_w \leq 6.3$ (5 from the L'Aquila earthquake, 3 from the Friuli aftershocks of September 1976, and 1 from the Umbria-Marche September 1997 mainshock). The strongest events in ITACA, i.e., the M_w 6.4 May 6 1976 Friuli and the M_w 6.9 November 23 1980 Irpinia earthquakes, were recorded at $R_{epi} > 10$ km.

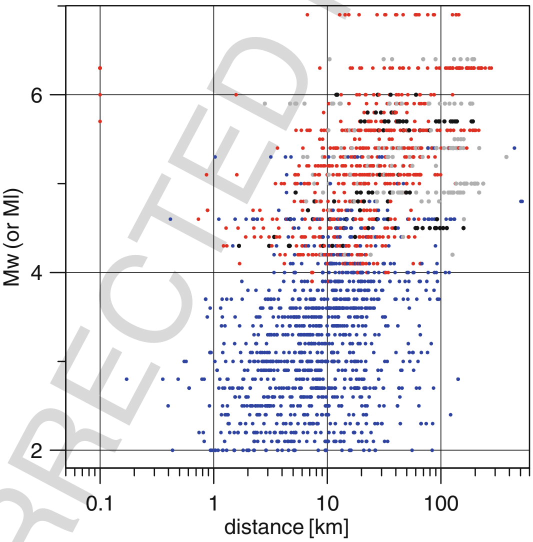

Fig. 8.1 Magnitude vs. distance (either Joyner-Boore for M > 5.5 or epicentral distance otherwise) distributions for the ITACA dataset. The records are grouped by focal mechanism (*blue*: normal; *gray*: reverse, *black*: *strike*, *blue*: unknown)

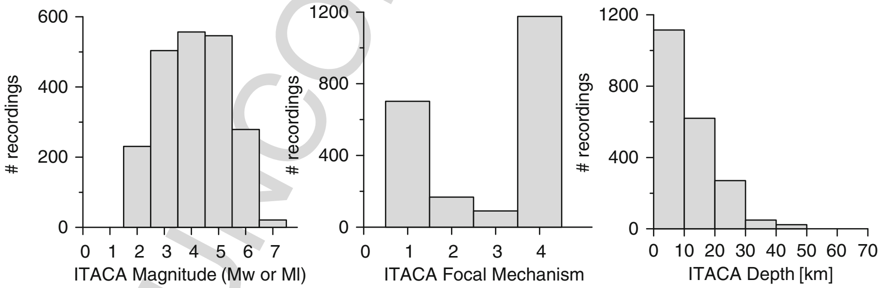

Fig. 8.2 Distribution of ITACA records plotted as a function (a) Magnitude; (b) focal mechanism (1: normal; 2: reverse, 3: *strike*, 4: unknown); (c) focal depth

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Distributions of records as a function of magnitude, focal depth and focal mechanism are plotted in Fig. 8.2. Most events with magnitude less than 4 have unknown focal mechanisms. For the strongest earthquakes, the focal mechanisms were assigned following the classification of Zoback [11], as described in Luzi et al. [8]. Among the strongest earthquakes, most of them were caused by normal faults in Central and Southern Apennines (namely, the Irpinia, Umbria-Marche and L'Aquila earthquakes), with focal depths less than 10 km. Earthquakes in NE Italy, including the Friuli seismic sequence, and in the Northern Apennines, are deeper and mainly characterized by a compressional tectonic regime. Finally, strike-slip events mainly occurred in Southern Italy, including the M_w 5.7 October 31 2002 Molise earthquake, at focal depths generally between 20 and 30 km.

As a whole, waveforms collected in ITACA were recorded by 665 strong-motion stations. Among these stations, 287 are presently not in operation, since they were either part of temporary networks or equipped with old analogue instruments, which were removed.

Station metadata were included in ITACA after collection of pre-existing data and field investigations performed during the S6 project and the ongoing S4 project. Geophysical and geotechnical information at the ITACA recording stations is available at different levels: from the simple geological description up to a complete geotechnical site characterization, including stratigraphic logs, V_S (S-wave) and V_P (P-wave) velocity profiles, dispersion curves, fundamental frequencies, site response functions, noise measurements etc. For most sites, based on strong and weak motions and noise measurements, it was possible to apply spectral ratio techniques, mainly Horizontal to Vertical (HVSR) and, in few cases, Standard Spectral Ratio (SSR), when a nearby reference station was available.

All ITACA stations are classified according to the EC8 [5] site classes, i.e., class A: $\mathbf{V}_{S30}$ 800 m/s, class B: $\mathbf{V}_{S30}$=360–800 m/s, class C: $\mathbf{V}_{S30} = 180$–360 m/s, class D: $\mathbf{V}_{S30}$ <180 m/s and class E: 5–20 m of C – or D-type alluvium underlain by stiffer material with $\mathbf{V}_S > 800$ m/s. However, since $\mathbf{V}_{S30}$ will be available only for about 100 stations at the end of Project S4, it was decided to denote by a star (∗) those stations that were classified only based on the geological/geophysical information available (S4 project – http://esse4.mi.ingv.it – Deliverable D4, 2009), but not on a direct measurement of $\mathbf{V}_{S30}$. Among stations with $\mathbf{V}_{S30}$ available at present, 8% were classified as A, 42% B, 27% C, 2% D and 21% E.

The distributions of peak ground acceleration (*PGA*) and velocity (*PGV*) values reflect the event-distance distribution (Fig. 8.3). With the exception of the L'Aquila seismic sequence, most records with largest peaks are from analogue instruments. A total of 360 waveforms (about 20% of the total) have $PGA > 50$ cm/s^2 while 160 recordings (about 10% of the total) have $PGV > 5$ cm/s. In both cases the maximum of two horizontal components was considered. *PGA* values exceeding 400 cm/s^2 were recorded at stations in the epicentral area, during the L'Aquila, Umbria Marche and Friuli earthquakes. The 1980 Irpinia earthquake generated the largest *PGV* (70 cm/s) at Sturno station (STR).

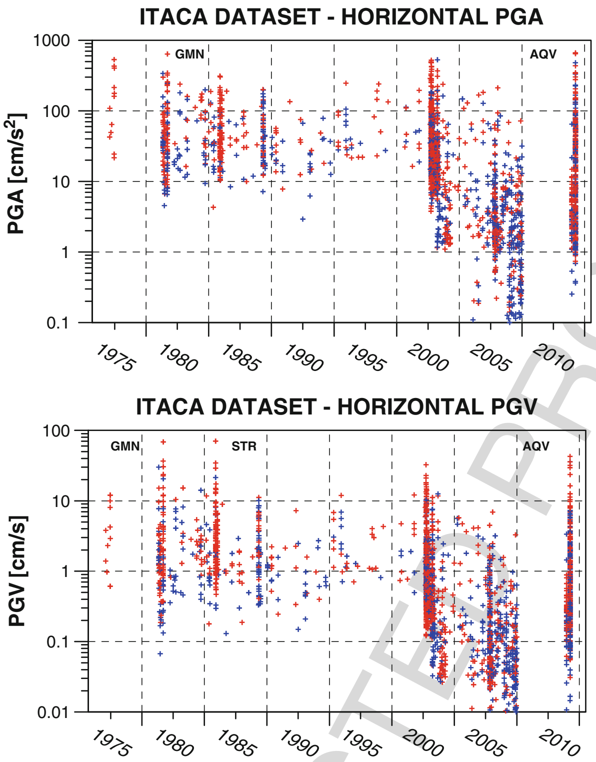

Fig. 8.3 Distribution with time of maximum horizontal *PGA* (*top*) and *PGV* (*bottom*) of ITACA records. The *blue* symbols represent values recorded at rock site (class A); the *red* ones at all the other site classes

8.3 Record Processing

The problem of defining a procedure to process acceleration time series recorded by analogue and digital instruments has been tackled since the first appearance of ITACA database. The proposed correction scheme involves the processing of analogue and digital records in different ways, with particular attention to the treatment of analogue data, as most of the strongest Italian events were recorded by analogue instruments.

The main steps of the processing procedure are described in Massa et al. [9] and involve: mean removal, baseline correction, instrument correction (for analogue data), band-pass filtering (with acausal filters) and integration of the processed acceleration in order to obtain velocity and displacement waveforms. This scheme was applied to each individual record, with the aim of preserving the low frequency content of the signals. Although the ITACA waveforms were treated by following the worldwide accepted techniques that aim to remove low and high frequency noise, the compatibility among acceleration, velocity and displacement was not guaranteed in the alpha version of ITACA. Within the revision activities to publish the beta version of the database, several points have been addressed, dealing with the quality and reliability of corrected records, namely:

- to check the accuracy and reliability of the frequency range of the corrected records and compare them with the corresponding records available in other international databases, such as PEER and European Strong Motion Database (ESMDB);
- to ensure the compatibility of corrected accelerograms, so that no further correction is required to obtain the velocity and displacement traces by single and double integration, respectively;
- to identify the late-triggered records, typically on the S-phase, that form a large portion of analogue records from small-to-medium magnitude earthquakes.

Based on the above discussions a novel procedure for processing the ITACA strong-motion records has been devised, with the objectives of providing a rational solution to the previous problems and of being robust as well as reliable enough to be effectively used for reprocessing of all the ITACA records, including the most recent ones from the Parma (December 2008) and L'Aquila (April 2009) earthquakes.

8.3.1 ITACA Processing Scheme

The diagram block of the new procedure is illustrated in Fig. 8.4. Its basic steps are the followings:

- baseline correction (constant de-trending);
- application of a cosine taper, based on the visual inspection of the record (typically between 2 and 5% of the total record length); records identified as late-triggered are not tapered;
- visual inspection of the Fourier spectrum to select the band-pass frequency range; whenever feasible, the same range is selected for the 3-components;
- application of a 2nd order acausal frequency-domain Butterworth filter to the acceleration time-series;
- double-integration to obtain displacement time series;
- linear de-trending of displacement;
- double-differentiation to get the corrected acceleration.

Note that zero-pads are added at the beginning and end of the signal before the acausal filter is applied [4]. However, this may pose several problems when using the corrected accelerograms, especially for engineering applications. As a matter of fact, very long initial zero-pads would most likely be removed by those end-users who are interested in using the waveforms for time-consuming non-linear time history analyses of dynamic response of soils and structures. As a consequence, the numerical simulations may start from non-zero initial conditions and present spurious trends in terms of input velocity and displacement, with the risk to compromise the reliability of results. To overcome this problem, it was decided to re-establish after filtering the original initial time-scale, whenever feasible. This is done by

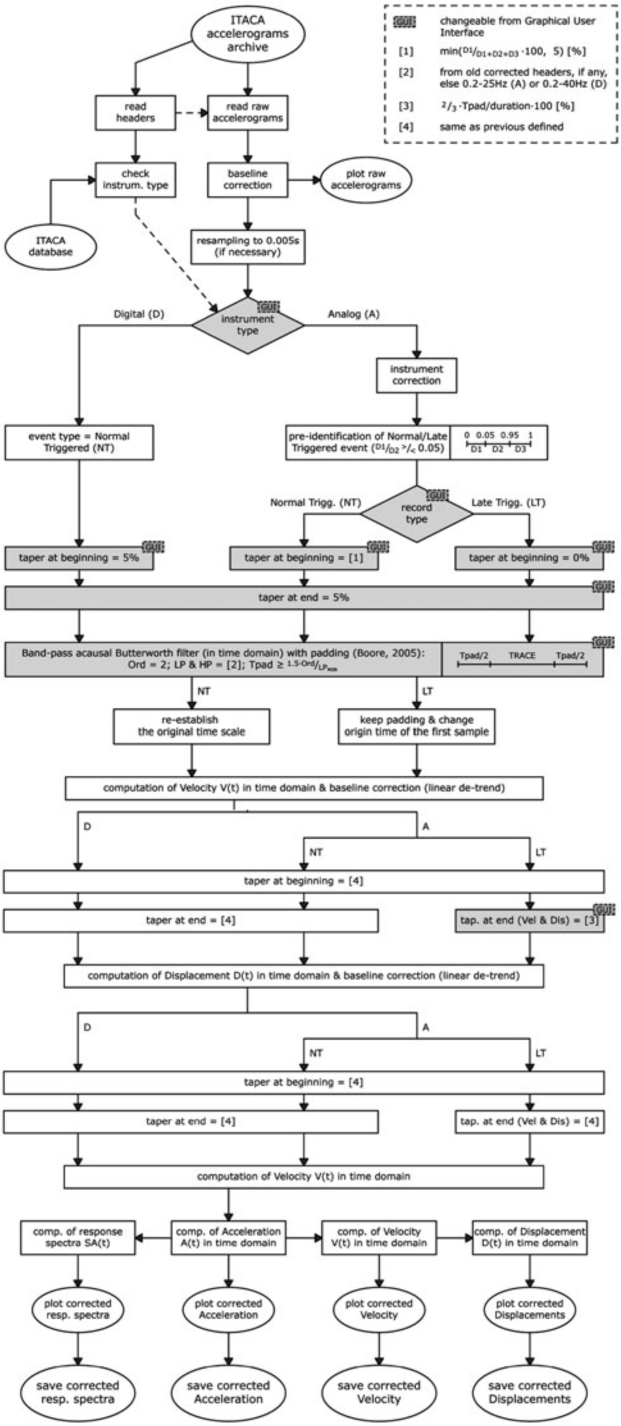

Fig. 8.4 ITACA data processing scheme

removing the zero-pads and by ensuring that the subsequent tapering of velocity and displacement will produce time histories starting from zero initial conditions. Otherwise, if tapering is not sufficient for this purpose, the initial zero-pads are retained. For late-triggered records, no taper is applied and zero-pads are kept.

The linear de-trending of displacement traces, and subsequent differentiation to obtain the corrected accelerations, ensures the compatibility of all corrected records, in the sense that the integration and double integration of the corrected accelerograms produce velocity and displacement time series with zero initial conditions and without unrealistic trends.

8.3.2 Comparison with Records from Other Sources

Three sources have been considered that contain the most important records from Italy, namely ITACA itself, the European Strong Motion Database (ESMDB, http://www.isesd.cv.ic.ac.uk/ESD/frameset.htm) and the PEER Strong motion database (PEER, http://peer.berkeley.edu/smcat). Only for L'Aquila 2009 earthquake the source external to ITACA was the CESMD (Center for Engineering Strong Motion Data, http://www.strongmotioncenter.org).

To clarify the major reasons of difference among records from various sources, Fig. 8.5 shows a comparison for the San Rocco record, NS component, of the

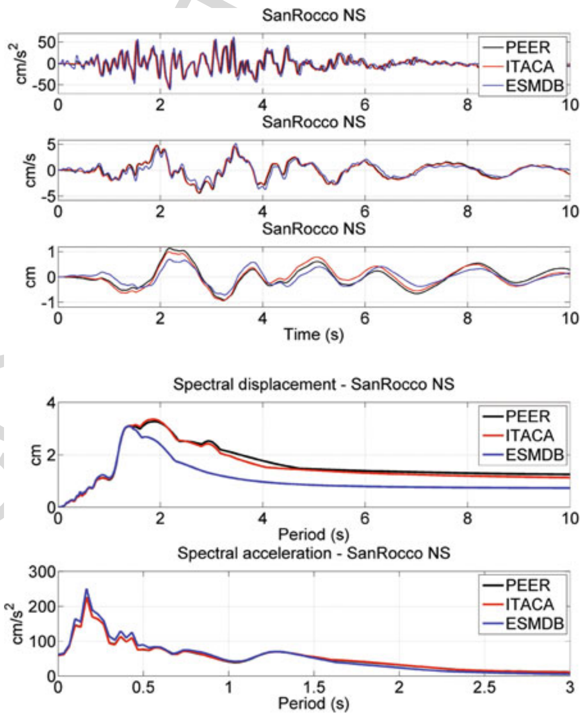

Fig. 8.5 Comparison of San Rocco corrected record, NS component, from the M_W6.1 Friuli aftershock of Sep 15 1976, 03:15 GMT, as available from ITACA, ESMDB and PEER databases. From *top* to *bottom*: corrected acceleration, velocity, displacement, spectral displacement and spectral acceleration

M_W6.1 Friuli aftershock of September 15 1976 (03:15 GMT). In this case, PEER and ITACA records are similar, with similar high-pass (HP) filter corners (0.1 and 0.15 Hz, respectively). None of these records have zero-pads at the beginning, but the tapering allows one to obtain compatible velocity and displacement time series.

On the other hand, the ESMDB record is not tapered, it is HP filtered at 0.45 Hz and keeps zero-pads at the beginning (not shown in the plot). If zero-pads were removed to re-establish the original time scale, the displacement would be affected by a trend.

As a second example, Fig. 8.6 illustrates the comparison of the corrected Bagnoli NS record of the M_W6.9 Irpinia earthquake in 1980. In this case, the HP corner

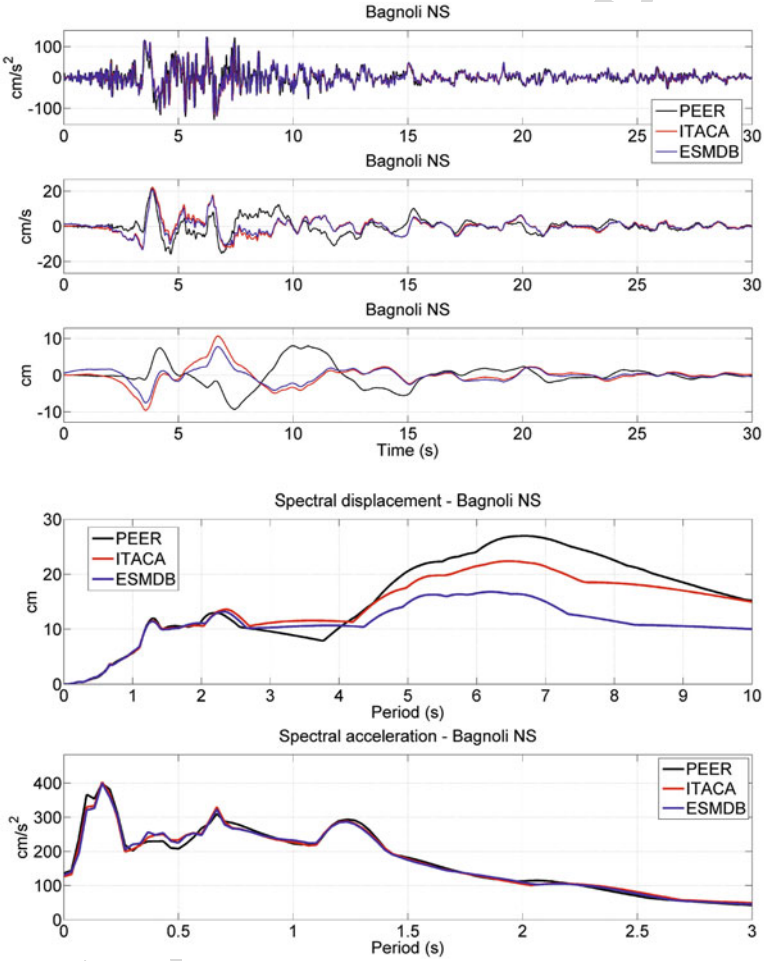

Fig. 8.6 As Fig. 8.5, for the NS component of Bagnoli corrected record, from the Mw6.9 Irpinia earthquake, 1980

frequency of corrected records are similar (0.1 Hz for both ITACA and PEER and 0.15 Hz for the ESMDB), but the PEER velocity and displacement traces are different from the other two.

Such a difference could be due to causal filtering of the record, affecting the phase of the signal. ITACA and ESMDB time series, both processed by acausal filter, are quite similar in this case, although the ESMDB record has zero pads at beginning that are not shown in the plot.

As a further example, Fig. 8.7 illustrates a case of corrected ground motion from digital records. Reference is made to the NS component of the AQV record of the M_W6.3 L'Aquila earthquake and the alternative source is the CESMD. In this case the HP frequency is 0.1 Hz for ITACA and 0.05 Hz for CESMD. The difference in the HP frequency is the reason of the clearer evidence of the acausal filter transient in the CESMD displacement trace. To avoid the onset of such spurious transients in the displacement waveforms from acausal high-pass filtering and to recover reliable permanent displacements from double integration of accelerations, records of L'Aquila were also processed using a baseline correction technique that consists of

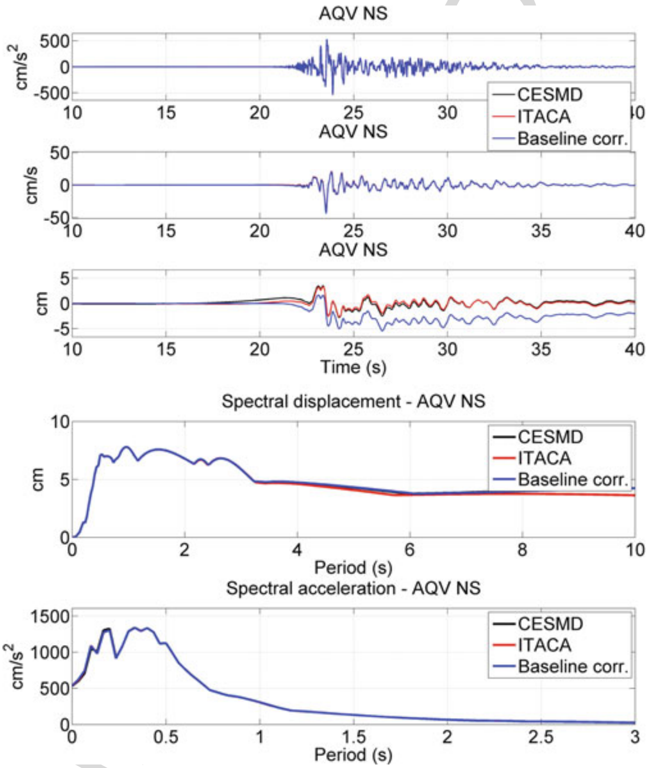

Fig. 8.7 As Fig. 8.5, for the AQV corrected record, NS component, from the M_W6.3 L'Aquila earthquake, 2009. Superimposed is the record corrected with a piecewise baseline on velocity to retrieve permanent displacements

least-squares fitting the velocity time histories by three consecutive line segments, and subsequently removing these trends from the velocity time histories [1]. The resulting permanent displacements were found to be consistent with the GPS and INSAR findings (Anzidei et al., 2009; Atzori et al., 2009). Note that long period response spectral ordinates are practically unchanged using the three different processing techniques, confirming the findings by Paolucci et al. [10] regarding the reliability of long period response spectral ordinates from digital accelerograms.

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Due to the space limitations of the paper, instead of documenting similar comparisons on a much larger set of records, we summarize here the most significant outcomes of such comparisons:

- for digital records, results of ITACA, PEER, ESMDB and CESMD processing are similar;
- for analogue records, ITACA and ESMDB provide similar results except for (i) a more conservative selection of the ESMDB band-pass frequency range in several cases, (ii) tapering on a longer portion of records in ITACA and (iii) the retention of zero-pads in the ESMDB records;
- ITACA and PEER analogue records practically coincide whenever the PEER records are processed by acausal filters.

8.3.3 Processing of Late-Triggered Records

A significant portion of analogue strong-motion records of ITACA consists of accelerograms triggered by the S-phase arrival (*late-triggered records*). Processing such records faces several major difficulties, especially because tapering of the initial part of the signal would inevitably cancel out some important portions of the signal itself. In the new version of ITACA, late-triggered records are identified by a specific field, so that the end-user may decide to query the database without considering such records.

To support the identification of late-triggered (LT) records in the processing stage, a criterion was introduced based on the cumulated Arias intensity function, $I(t)$. For this purpose, each record is subdivided into three portions, as shown in Fig. 8.8, where D_1 is the time between the starting of the record and the time t_{05} for which $I(t_{05})=0.05$, and $D_2 = t_{95}–t_{05}$, where $I(t_{95})=0.95$. It was found that most of the LT records in ITACA could be identified by the condition $D_1/D_2 < 0.05$, although visual inspection of the records is always required.

Once the LT record has been identified, the procedure for correction is similar to the one for NT records, except for the following:

- the initial part of the record is not tapered;
- the zero-pads are always retained.

We can gain an interesting insight about the quality of LT records, by considering two co-located stations in Nocera Umbra, an analogue one (denoted by NCR in ITACA) and a digital one (denoted by NCR2). Table 8.1 lists the events for which

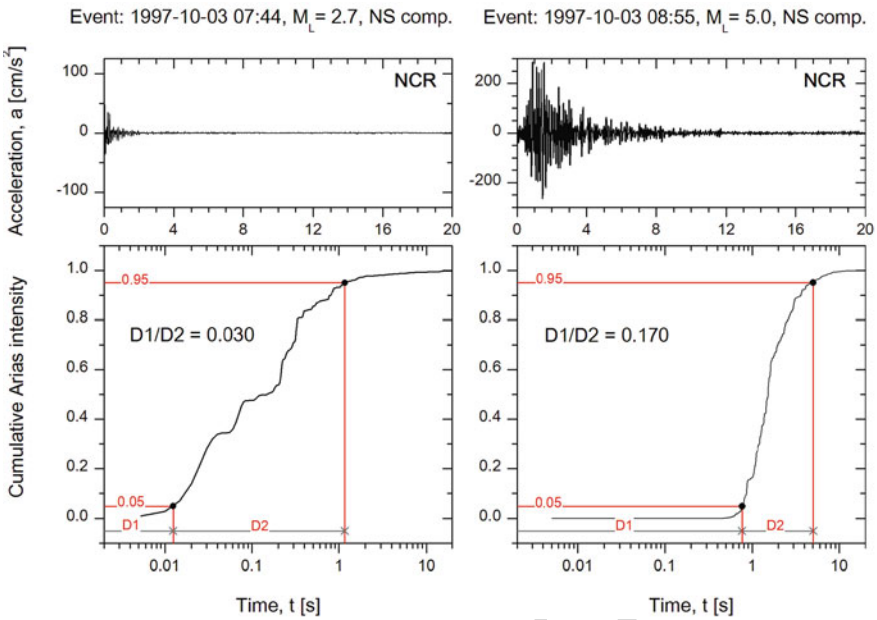

Fig. 8.8 Two analogue records from the same station NCR, identified as *late triggered* (LT, *left*) and *normally triggered* (NT, *right*)

both digital and analogue records are available, as well as the corresponding D1/D2 ratios and the N_d(0–0.5 s) parameter between the NCR and NCR2 response spectra normalized by NCR2. The latter parameter (N_d) measures the average difference of the response spectral ordinates in the 0–0.5 s period range. Therefore, N_d=0 means

Table 8.1 List of events and parameters associated to analogue records at NCR station

			D_1/D_2		N_d (0–0.5 s)		
ID	M_w	M_L	NS	EW	NS	EW	Class. rec.
19971003_074404		2.7	0.030	0.019	0.55	0.25	LT
19971003_121624		2.9	0.003	0.006	0.81	0.42	LT
19971003_124844		3.1	0.011	0.017	0.56	0.39	LT
19971007_012434	4.2	4.1	0.005	0.108	0.02	0.17	LT
19971007_050956	4.5	4.3	0.036	0.028	0.68	0.49	LT
19971012_110836	5.2	5.1	0.024	0.031	0.16	0.10	LT
19971014_075405		3.3	0.008	0.011	0.42	0.01	LT
19971014_152309	5.6	5.5	0.059	0.099	0.10	0.06	LT
19971108_153153		4.1	0.014	0.034	0.85	1.32	LT
19980405_155221	4.8	4.5	0.059	0.050	0.05	0.07	LT
19971002_105956	4.7	4.1	0.073	0.082	0.12	0.07	NT
19971003_085522	5.2	5.0	0.170	0.164	0.09	0.10	NT
19971006_232453	5.4	5.4	0.346	0.398	0.07	0.09	NT
19971011_032057		3.7	1.163	0.526	0.12	0.04	NT

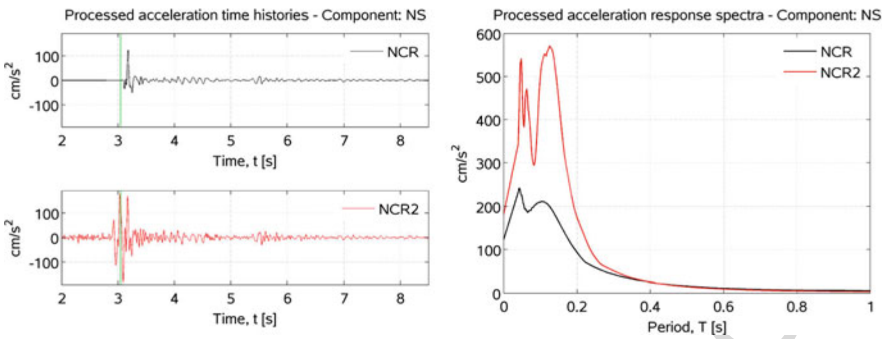

Fig. 8.9 Analogue (NCR) and digital (NCR2) corrected accelerograms of event 19971014_075405 (NS component in Table 8.1)

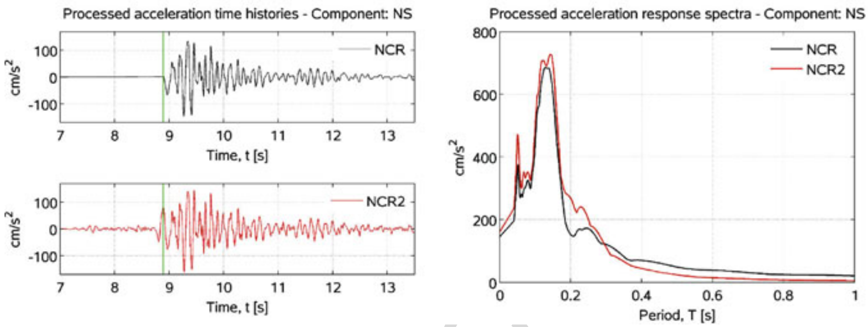

Fig. 8.10 Same as Fig. 8.9 for the NS component of event 19980405_155221

that the analogue and digital spectra coincide, while N_d=1 means that the average difference is 100%.

Examples of the corrected LT records at NCR, with the corresponding digital co-located records of NCR2 and the corresponding 5% damped response spectra of acceleration are shown in Fig. 8.9 and Fig. 8.10. It is clear that the case plotted in Fig. 8.9 illustrates a very poor quality record ($N_d = 0.47$, according to Table 8.1), while the corrected analogue accelerogram in Fig. 8.10 ($N_d = 0.05$) approaches the spectral ordinates of the digital record and can be considered usable for engineering applications.

Another interesting illustration about the quality of the LT records and their relationship with the proposed parameter D_1/D_2 is shown in Fig. 8.11 that shows the plot of N_d vs. D_1/D_2. This plot suggests that the proposed rule-of-thumb $D_1/D_2 < 0.05$ to identify LT records is rather satisfactory, but it is difficult to use the same parameter D_1/D_2 to discriminate between "good" and "poor" quality LT records. A similar conclusion was drawn by Douglas [7], when considering a similar criterion to check the quality of LT records, based on the bracketed duration for acceleration values larger than 0.005 g.

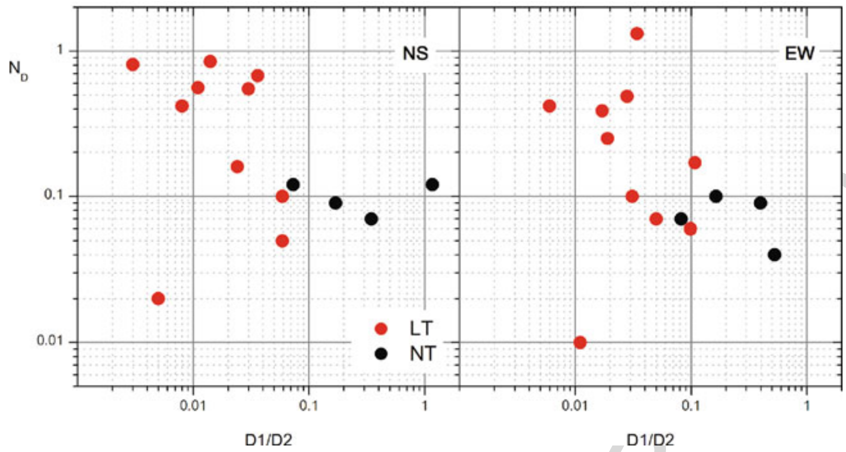

Fig. 8.11 Variation of the index N_d(0–0.5 s) as a function of the ratio D_1/D_2 for the records of NCR station

8.4 Conclusions

A notable effort has been made in the recent years to collect and organize in a single, informative and reliable Italian strong-motion database by the joint cooperation of the Italian Department of Civil Protection, the Istituto Nazionale di Geofisica e Vulcanologia, and several University research groups. The ITalian ACelerometric Archive ITACA contains most of the strong motion accelerograms recorded in Italy since 1972. The final release of ITACA from Project S4 will be available by June 2010.

The quality and the level of station and event metadata were appreciated by many researchers and professionals who accessed ITACA after the L'Aquila earthquake. The rapid response of ITACA for collecting, processing and disseminating the data of this earthquake from Italian networks was also appreciated by the professional community.

Among different topics addressed in Project S4 to improve ITACA, this paper illustrated the main issues that were faced to provide reliable corrected accelerograms from a large set of records with a wide variation in quality and amplitude that are usable both for the engineering and research communities.

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Chapter 8

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