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Project S4: ITALIAN STRONG MOTION DATA BASE

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Deliverable # D15

Record processing in ITACA

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1. Scope and Description of the Deliverable

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. (2009) 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.

1.1 ITACA processing scheme

The diagram block of the new procedure is illustrated in Fig. 1. 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 (Boore and Bommer, 2005). 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 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.

1.2 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. 2 shows a comparison for the San Rocco record, NS component, of the 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 Hz 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. 3 illustrates the comparison of the corrected Bagnoli NS record of the M_w6.9 Irpinia earthquake in 1980. In this case, the HP corner 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.

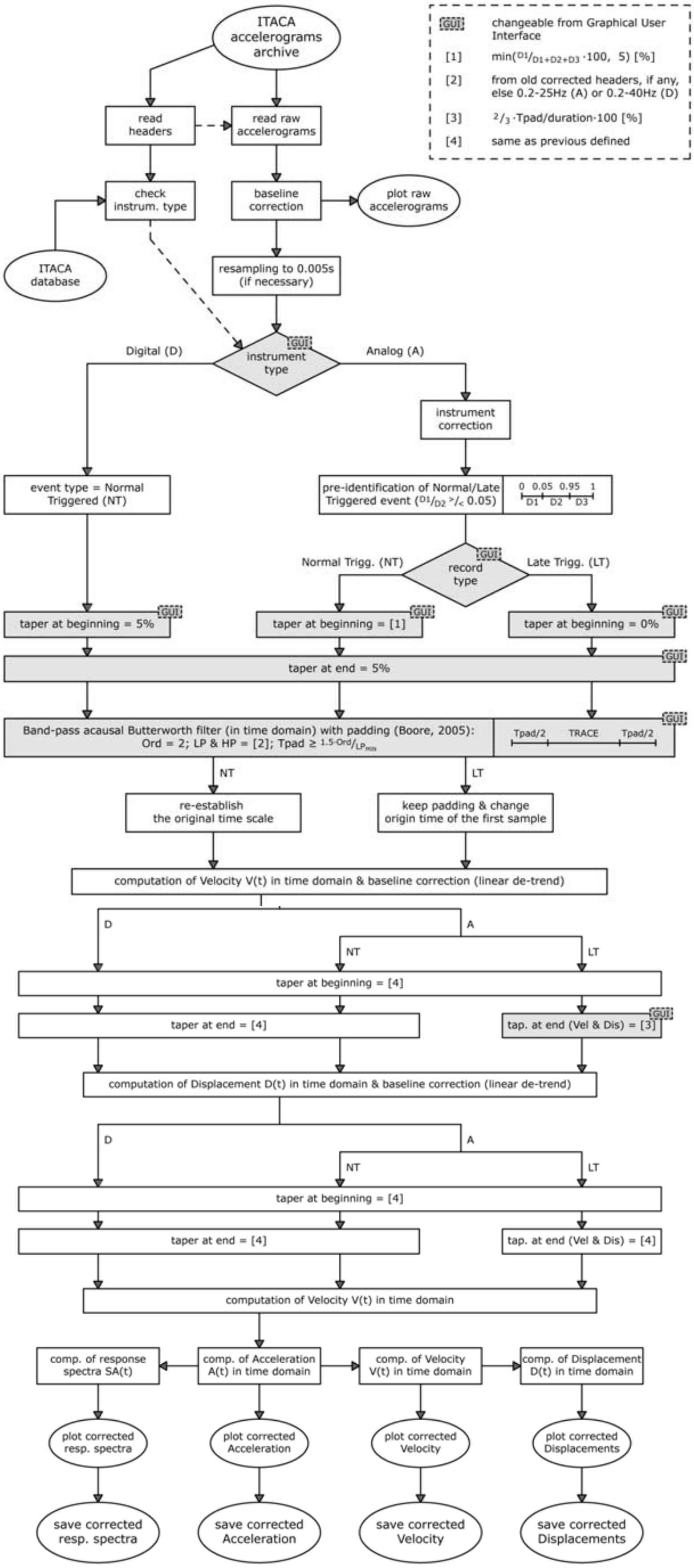

Figure 1. ITACA data processing scheme.

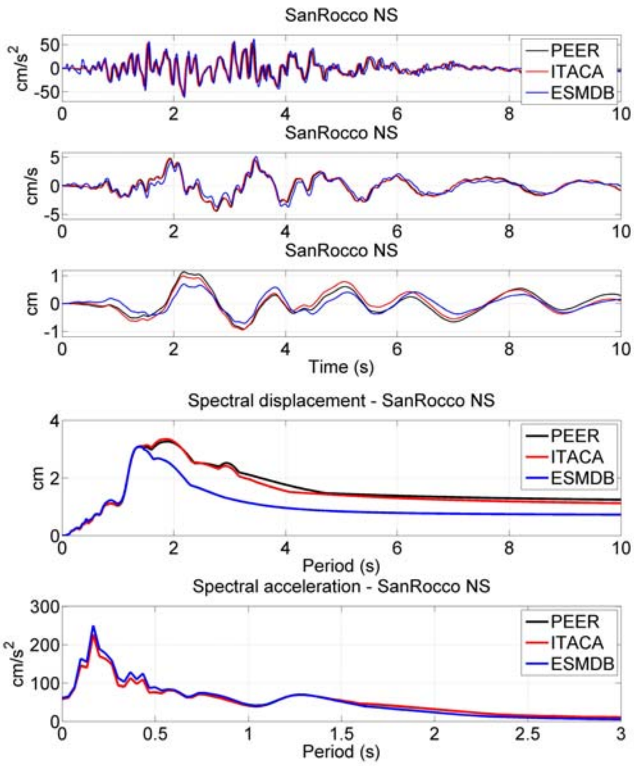

Figure 2. Comparison of San Rocco corrected record, NS component, from the M_w6.1 Friuli aftershock of Sep 15 1976, 03:15 GMT, as available from ITACA, ESMDB and PEER databases. From top to bottom: corrected acceleration, velocity, displacement, spectral displacement and spectral acceleration.

As a further example, Fig. 4 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 least-squares fitting the velocity time histories by three consecutive line segments, and subsequently removing these trends from the velocity time histories (Ameri et al., 2009). 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. (2008) regarding the reliability of long period response spectral ordinates from digital accelerograms.

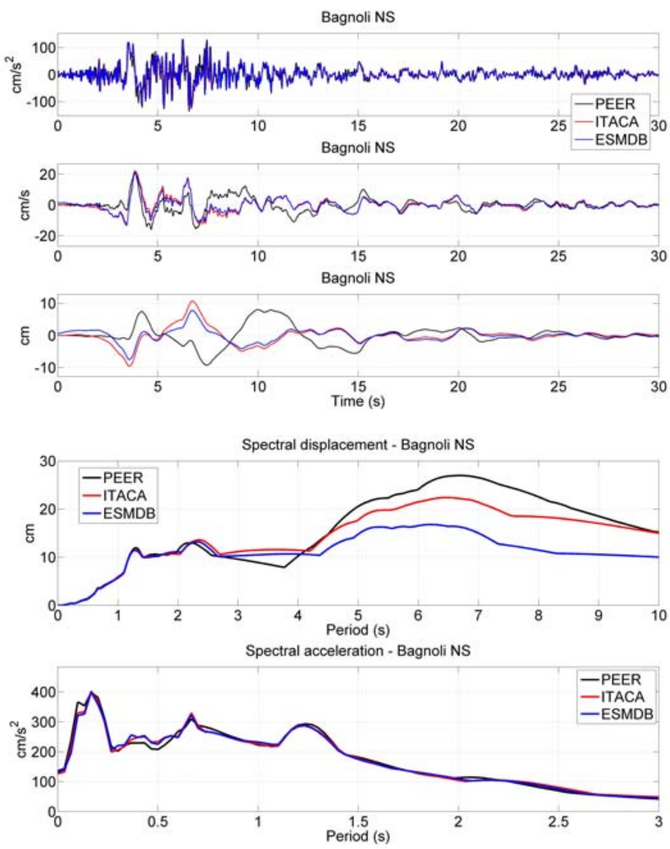

Figure 3. As Fig. 2, for the NS component of Bagnoli corrected record, from the M_w6.9 Irpinia earthquake, 1980.

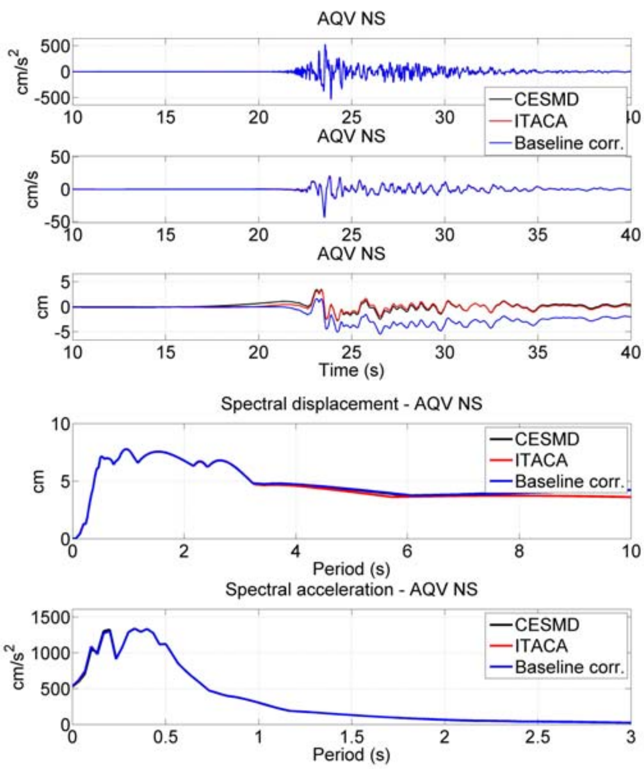

Figure 4. As Fig. 2, for the AQV corrected record, NS component, from the M_w6.3 L'Aquila earthquake, 2009. Superimposed is the record corrected with a piecewise baseline on velocity to retrieve permanent displacements.

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.

1.3 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. 5, 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.

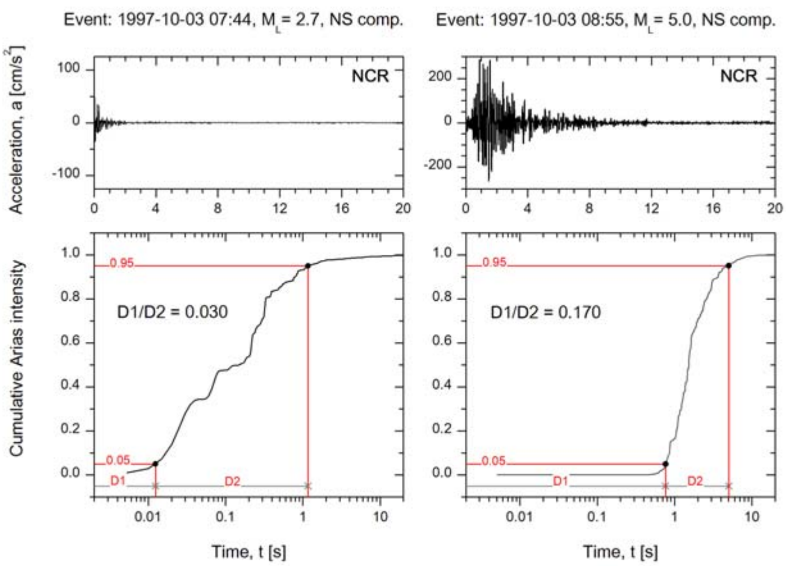

Figure 5. Two analogue records from the same station NCR, identified as *late triggered* (LT, left) and *normally triggered* (NT, right).

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 1 lists the events for which both digital and analogue records are available, as well as the corresponding D_1/D_2 ratios and the N_d(0-0.5s) 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 0-0.5s period range. Therefore, N_d=0 means 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 Figs. 6 and 7. It is clear that the case plotted in Fig. 6 illustrates a very poor quality record (N_d = 0.47, according to Table 1), while the corrected analogue accelerogram in Fig. 7 (N_d = 0.05) approaches the spectral ordinates of the digital record and can be considered usable for engineering applications.

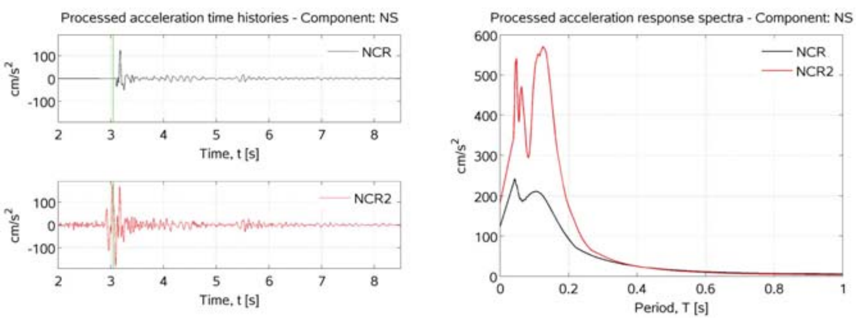

Figure 6. Analogue (NCR) and digital (NCR2) corrected accelerograms of event 19971014_075405 (NS component in Table 1).

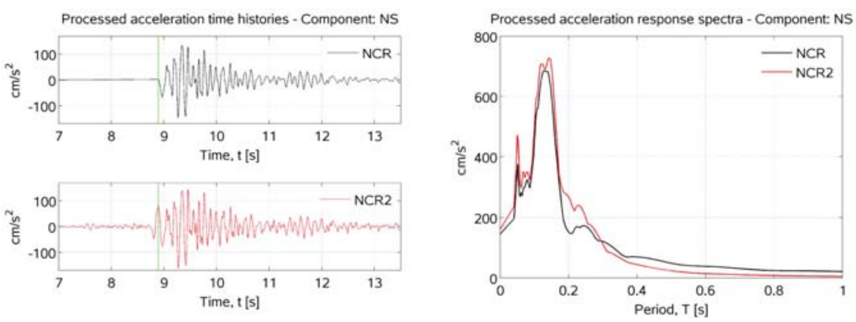

Figure 7. Same as Fig. 6 for the NS component of event 19980405_155221.

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 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 (2003), when considering a similar criterion to check the quality of LT records, based on the bracketed duration for acceleration values larger than 0.005g.

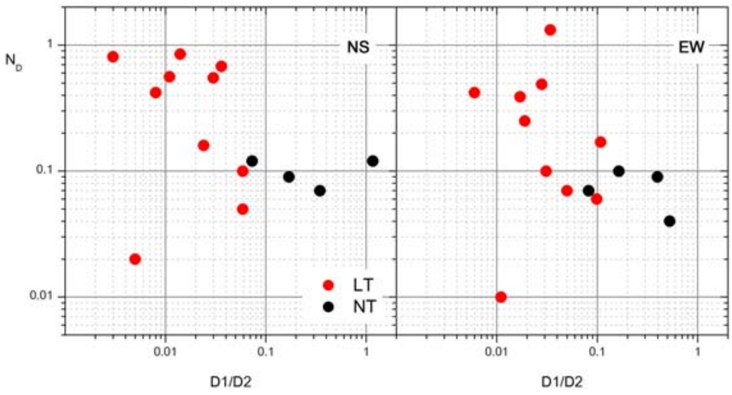

Figure 8. Variation of the index N_d(0-0.5s) as a function of the ratio D_1/D_2 for the records of NCR station.

Table 1. List of events and parameters associated to analogue records at NCR station

			D_1/D_2		N_d (0-0.5s)		Class.
ID	M_w	M_L	NS	EW	NS	EW	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

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2. Availability/Restrictions and contact person

This report has been also published in a more complete form in the Proceedings of the 2nd Euro-Mediterranean meeting on Accelerometric Data Exchange and Archiving, Ankara, November 2009.

3. Relevance for DPC and/or for the scientific community

The processing procedure has been introduced to encompass the different sources of errors due to the wide variability of quality of ITACA records. The compatibility of all records makes these accelerograms usable for a wide range of engineering applications, including dynamic soil-structure interaction studies, in which the unrealistic values of ground displacements may prevent reliable analyses of seismic response of geotechnical structures.

4. Changes with respect to the original plans and reasons for it

This Deliverable was not planned at start of Project S4.