ACQUISITION AND PROCESSING OF TIME-HISTORY RECORDS FROM SHAKING TABLE TESTS ON MASONRY SPECIMENS

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ABSTRACT :

Due to the crash of the computer driving the ENEA shake-table, only paper sheets and images documented the results obtained for the first of two masonry specimens tested. Raster images were digitized by means of a special purpose algorithm and digital data showed the need to be processed so as to improve time origin sinchronization and measurements coherence. The test results for the second masonry specimen were instead recorded on a computer and a backup copy of all files (input and recording from all channels – accelerometers and LVDT) was immediately made. Unfortunately, the input record was not aligned (same time origin) with the other channels. To solve this problem all time-histories were processed and time-shifted so as to maximize the cross-correlation function and the measured coherence.

KEYWORDS: Shake-table tests, masonry structures, PSD, CSD, Coherence of digitized signals.

1. INTRODUCTION

As already described in a previous paper [Rinaldis et al., 2008], experimental tests on a shake-table sited at the Casaccia research center of ENEA were scheduled in 1990s. The tested specimens were two masonry arches made of regional tuff. The whole research activity was subdivided in the following steps:

a) design seismic tests and characterizations of the first tested specimen up to the collapse;
b) design seismic tests and characterizations of the second tested specimen up to a fixed damage level (b1); reinforcement of the structure by means of inserting (b2); repetition of the test up to the collapse (b3);
c) design tests and devices for scaled specimens of the arches;
d) adapt designed tests and devices to the scaled specimens of the arches.

Up to the today date only steps a) and b) were completed. Moreover, due to the crash of the computer driving the shake-table, only paper sheets and images documented the results obtained for the first specimen. The tests on the second specimen were instead recorded on a computer and a backup copy of all files (input and recording of all channels – accelerometers and LVDT) was immediately made. Unfortunately, the input record was not aligned (same time origin) with the other channels [Clemente et al., 1999]. To solve this problem all time-histories were processed and time-shifted so as to maximize the cross-correlation function and the measured coherence.

Much more efforts required the recovering of records obtained during the shake-table tests of the first specimen. In fact, only the print out of recordings (lasting 16 seconds) and the Fourier amplitude and phase (in a limited frequency range) were available for the assessment of the structure frequency. All the collected print out were digitized and records of corresponding channels recovered. Then PSD, CSD and coherence functions were evaluated. The comparison between the variation of the first resonance frequency on the two specimen was utilized for the selection of the frequency window were the spectra should be evaluated.

2. SPECIMEN 1: RECORDS RECOVERING PROCEDURE

Recovering of information (either seismological or structural) from ancient images has been already faced

[Bongiovanni et al., 1987] as well as digitization errors and frequency band limits [Rinaldis et al., 1986]. Meanwhile, the processing of recordings obtained from the scanning of images presented some peculiarities that should be exanimated. All records were digitized with a 300 dots/inch scanner density. Then records were analysed and the time-histories produced by a peak-picking procedure and applying an half-cosine band-pass filter with frequencies cut-off 0.5-32 Hz. To evaluate the procedure efficiency, a reverse procedure was applied in order to produce a print out of a known digital record, in a similar condition (the most difficult step was to select a printer with similar print out quality). Then the original signal and its digitised version were compared in time and frequency domain. Figure 2 shows that a departure on the frequency content of the digitised version respect to the original signal is visible at frequencies larger then 20 Hz. Taking in account that time-histories were recorded with a sampling time of 50 points per second (i.e. the Nyquist frequency is 25 Hz) this result seems to be acceptable. A better fit could be obtained if Fourier amplitude and phase of the original signal will be fitted to the digitized version. Obtained results of the structure dynamic characterization should not be trusted as in the case of use original time-histories.

3. DIGITIZATION ERRORS AND NOISE MODEL

The digitization of a signal consisted of two operations: sampling and quantization. Sampling defined the time instant at which the signal is to be observed, while quantization was the digital conversion of continuous signal coordinates, at the sampled points, into a sequence of numbers. The sampling of an analogic record is affected by a positioning error when its A/D conversion (quantization) is subjected to the rounding effect.

In order to consider positioning error and rounding effect in the automatic digitization, Figure 1 shows the trace of the record and the scanner elements. As first hypothesis, the arrays of photodiodes were supposed orthogonal to the trace and standing in a certain point. The trace is all black, the borders are well defined and its thickness is known exactly. The quantization levels of the system cross the photodiodes at their centre, the dotted lines delimitate the region of the trace where the photodiodes have the logic value "0". These lines were referred as the "logic borders" of the trace.

Their position, for an assigned thickness of the trace, depends on the threshold value Vs. For each scan, the system provides a tern of integer values n, FI, FS that correspond respectively to the order number of each sequential array of scanner shooting and the order number in each array of the first and the last photodiodes obscured by the trace. By this tern it is possible to know the coordinates of the sampled point. The time coordinate is:

$$t_n = k_1\, n\, \Delta x \qquad (1)$$

where k_1 is a scaling factor and Δx is the sampling interval on the x-axis; the typical value of Δx is therefore 25 μm.

The first and last photodiodes obscured by the trace have ordinates respectively:

$$y_{FI} = h\, FI_n$$
$$y_{FS} = h\, FS_n \qquad (2)$$

where h, referring to Figure 1, is the height of one photodiode. The ordinate of the sampled point y_n was normally assumed to be the centre of the trace that is :

$$y_n = [(y_{FI})_n + (y_{FS})_n]/2 \qquad (3)$$

$$\varepsilon = Y_n + y_n \quad (4)$$

$$\varepsilon = [(y_{FI} + \Delta y_i + y_{FS} + \Delta y_s) - (y_{FI} + y_{FS})]/2 \quad (5)$$

where Δy_i and Δy_s measured the distance from the real border and the logic border of the trace.

The maximum positioning error is:

$$\varepsilon_{max} = [(y_{FI} + h + y_{FS} + h) - (y_{FI} + y_{FS})]/2 = h \quad (6)$$

ε_{max} is equal to the dimension of a photodiode, that is 25 μm. The distribution function of ε is constant in the range (O,h) because the distribution function of Δy_i and Δy_s are independent and ranging from (O,h). In an similar way, stated that the error for yFI is Δy_i and for yFS is Δy_s, it is possible to state that the maximum positioning error in the peak-picking algorithm will be h as well.

It is easy to recognize that these results are valid for any position of the trace with respect to the array of the camera. For components of the trace records that have wavelength greater than 50 μm, i.e. with frequency less than 200 Hz, ε_{max} is also independent from the motion of the scanner. The rounding effect due to the quantization levels of the scanner is of the same order of magnitude of the positioning error. The comparison between the values of positioning error and rounding effect due to the automatic digitization and an handmade digitization showed that the maximum positioning error ε_{max} related to the automatic digitization is independent from the thickness of the trace and is 25 μm.

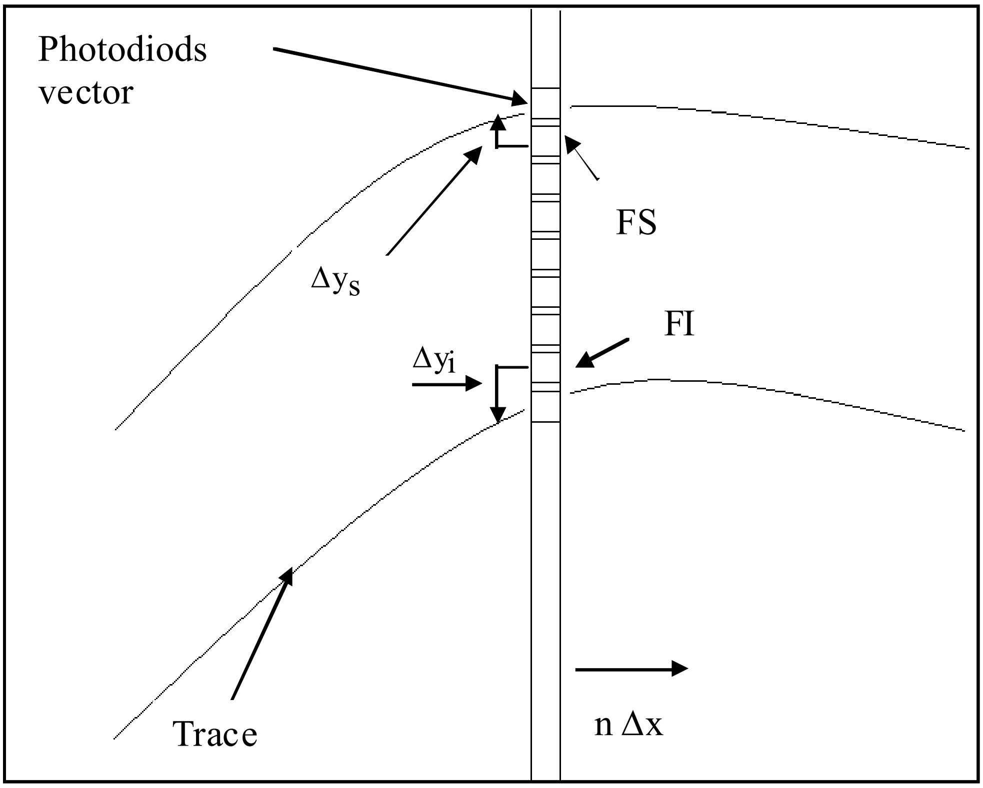


Fig. 1: Record trace and scanner position error evaluation.

4. PROCESSING OF RECORDINGS FROM SPECIMEN 2 AND EVALUATION OF STUCTURES DYNAMIC BEHAVIOUR

When only the graphical output of dynamic measurements are available, the simplest procedure to estimate the frequencies of structures is the peak-picking method, which is based on the calculation of the Power (PSD) and Cross Spectral Densities (CSD) of the recorded signals, by the use of Discrete Fourier Transform (DFT). At the natural frequencies, two simultaneously recorded output signals can be in phase or 180 degrees out of phase and the coherence function shows values close to one.

All the time histories were digitised at the sampling time step of 0.02 s. Each record were analysed in time and frequency domain, computing the power spectral density (PSD) Sii, the cross power spectral density for each interesting couple (CSD) Sij and the coherence function and the transfer function. By a MATLAB routine, for each pair of accelerometric sensors, the auto and cross-spectrum were calculated (the latter in amplitude and phase) in addition to the coherence. As shown both by time-histories and spectra, the reference trace was not aligned with other recordings. In order to improve the consistency of the measure, the origin of time-history of the reference trace was shifted and compared to the other records so as to maximize the correlation coefficient. was calculated. In this way, at the end of processing, time-histories and spectra of the two specimens were obtained.

One of the main goals in testing two different specimens was to study the repeatability of shake-table tests on masonry specimens. Thus, to avoid difference due to the manufacture, the specimens were built at the same time with similar material (block of regional yellow tuff and poor mortar) by the same workers.

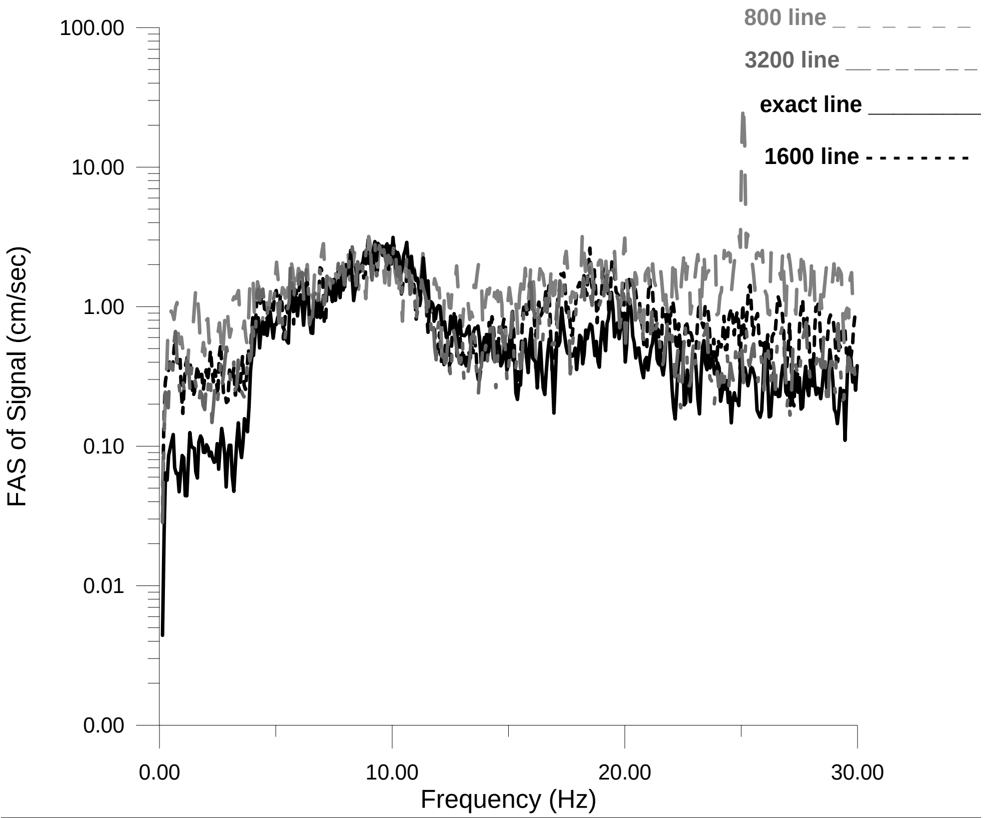


Figure 2. Comparison between the FAS of the test signal and some digitized versions of the corresponding images.

The first specimen was tested on November 1993 and the tests on specimen 2 were scheduled 3 months later. Unfortunately the tests on specimen 2 were instead executed almost 3 years later on May 1996. The changes in the dynamic behaviour of the two masonry arches subjected to successive base acceleration time histories, characterized by the same shape but with an increasing intensity, showed large discrepancies probably due to the decrease of the mechanical properties of the mortar [see Fig. 1 in Rinaldis et al., 2008]. The experimental analysis pointed out that the decrease of the first resonance frequency of the structures was not progressive but concentrated in three phases. The first cracks corresponded to a reduction of 18% in the first frequency, while the final frequency was almost half the initial value.

5. TEST T1 (SPECIMEN 2) AND T16 (SPECIMEN1)

Tests on the specimens were of different intensity stepping [Rinaldis et al., 2008]. In particular specimen 2 was tested with a larger value in the excitation increment, which was applied only in the lateral direction. Each test was followed by the dynamic characterisation, in order to evaluate the changes in structural properties and to analyse the effects of the damages. The characterisations were performed by soliciting the structure with a white noise input. The characterization following Test 1 (C1) for specimen 2 and Test 16 (CRTT16LAT) for specimen 1, gave a similar value of first resonance frequency. Figure 3(a-b) shows a comparison between the PSD, CSD, TF and coherence for the records obtained at similar sensor position.

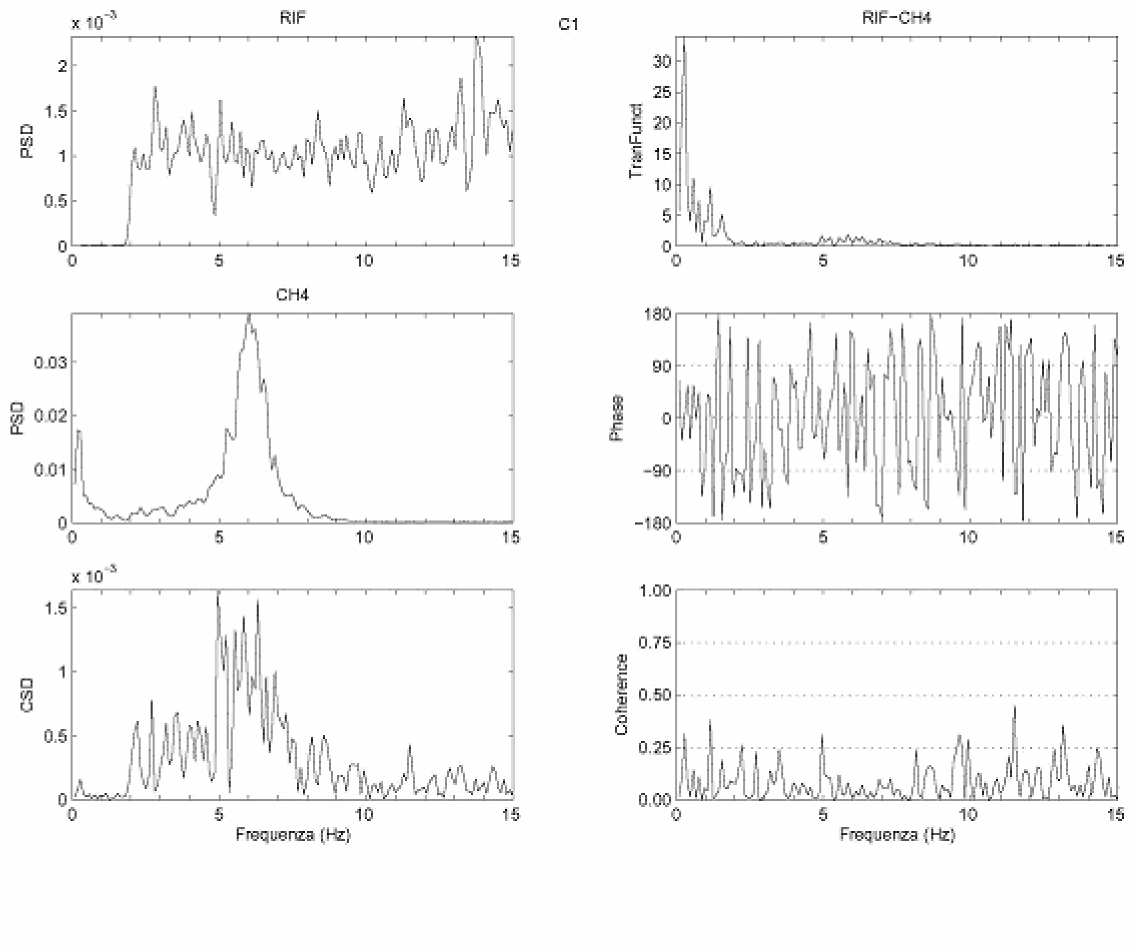
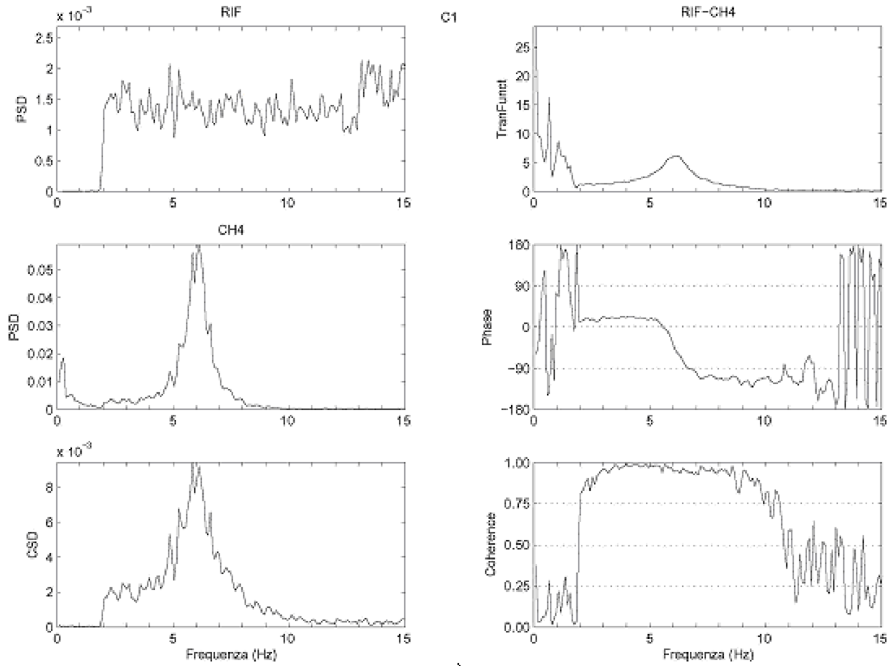
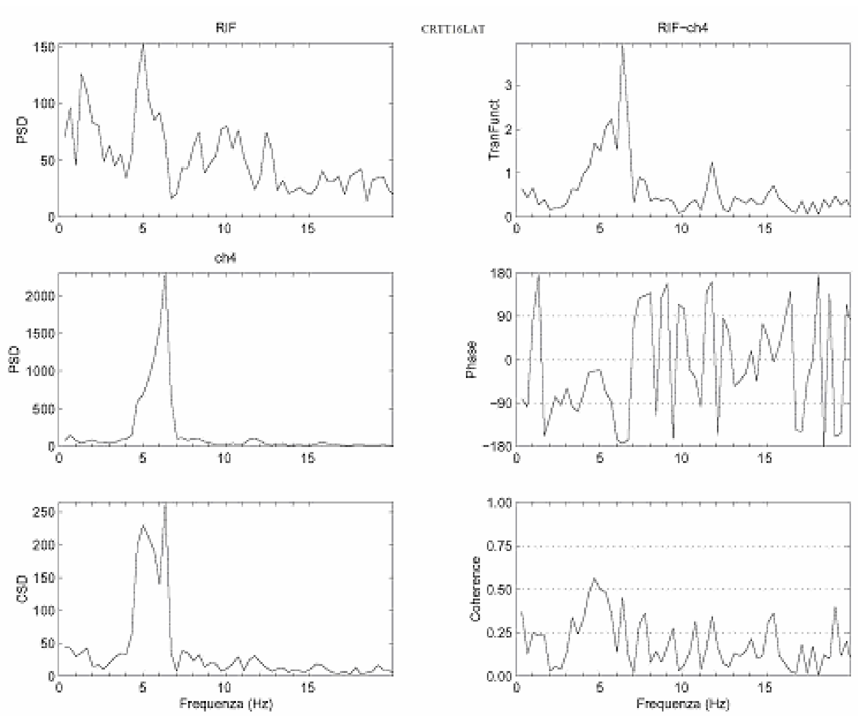


Figure 3. PSD, CSD, TF,Phase and Coherence of C1 (specimen 2); data before time-shifting.

Figure 3, compared with Figure 4 a), shows the time-shifting influence on the coherence function. The time-shift is due to the misallignement of the reference sensor time origin. Instead, the Coherence function of Figure 4(b) is very low probably due to the time shifting introduced by the scanning of the image. Much more interesting is the fact that the phase of CSD in Figure 4(b) (first specimen) seems to evidence, at frequency of 6.1 Hz, a torsional mode (phase = - 180°) when the phase of CSD in Figure 4(a) (second specimen) seems instead to evidence, at frequency of 6 Hz, a translational mode (phase = 0°).



a)



b)

Figure 4 (a-b). Comparison between the PSD, CSD, TF,Phase and Coherence of C1 (specimen 2) and CRTT16LAT (specimen 1).

6. CONCLUSIONS

The analysis of nowadays available acceleration time-histories recorded by sensors placed on two masonry specimens during shake-table tests performed between November 1993 and May 1996, was affected by the storing supports of original data. The records relative to the first specimen were available only on analogic support (paper). An analogic to digital conversion procedure was therefore performed and analyzed; the output errors was estimated and their influence at very high frequency, larger then 200 Hz, was proved. A peak-picking algorithm was introduced in the conversion procedure; the errors at high frequency (≥ 100 Hz) were eliminated by a band-pass filtering of data at 0.5-30 Hz. A further reverse test of the conversion procedure (based on the production of an analogic record from a known digital record, the digitalization of the trace and its reconversion in digital form by the peak-picking algorithm) showed that the global processing preserved the record content up to 20 Hz. Records of the second specimen were instead available on digital support but the reference record had not the same time origin of the other traces. The time origin of the reference record was recovered so as to maximize the cross-correlation coefficient with the others channels.

The processing of records obtained during the shake-table tests of two masonry specimens, which were characterized by the same structure, evidenced a quite different dynamic behavior as well as the indication of different excited mode motion for similar input motion. Moreover, the digital conversion of analogic records related to the first specimen was very promising in view of the results obtained by a preliminary comparison with the second specimen frequency analysis. A time-shifting of time-histories at every recording position, with respect to the reference trace, was found necessary in order to obtain a more suitable coherence function. Finally, the adopted peak-picking technique furnished the FAS and phase from analogic images which can be compared with the FAS and phase of the digitized time-histories.

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