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MEASUREMENT AND ANALYSIS OF TRAIN NOISE DETECTED ON A BUILDING FAÇADE.

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ABSTRACT

Noise produced by the transit of a train is affected by many variables: wheel-rail contact, engine, aerodynamic noise, random events, etc.. Some of these components, such as wheel-rail contact and aerodynamic noise are strongly dependent on high velocity, while other components, such as noise due to engines and auxiliary devices, are relevant in a low velocity regime, especially in proximity of a railway station, in the approaching and leaving phases.

In this paper we describe both an experimental activity regarding the measurements of noise produced by low velocity trains and detected on a building façade, close to a railway station at night time, and a semi-quantitative theoretical model which gives the principal shapes of freight trains in various dynamical situations.

At this stage of the study, we focus on different types of trains and of running conditions, evaluating their influence on the time history by means of comparisons between software predictions and experimental measurements. The experimental method chosen rely upon the simultaneous detection of the acoustic signals detected by two receivers placed some 30 meters apart and linked to the channels of a class 1 Measuring System.

KEY WORDS

Noise, railway, simulation model, time history, two channels analysis

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INTRODUCTION

During last years, interest on noise pollution had a significant growth in Europe. Many models have been developed in order to offer a solid basis to the development of noise control rules. Therefore, compared with other environmental problems, noise's one must be still deeply investigated.

Existing data are difficult to compare since different techniques and descriptors are used for their measurement.

The most complete information was collected by the Organization for Economic Cooperation and Development (OECD) in 1993 for 14 European countries. More recent studies show that 17–22% of the population of the European Union (EU) are daily exposed to traffic noise exceeding the tolerance limit of 65 dBA [1, 2, 3]. Another 170 million citizens live in so-called "gray zones" where noise levels within the range 55–65 dBA cause serious disturbance, especially at night-time.

Recent European policy regarding noise pollution is trying to work on the harmonization of data analysis methods. The aim is to draw up "noise maps" and define threshold values. As far as the railways are concerned, a regulation on admissible noise levels was presented in 1993 and soon withdrawn by the Commission in order to let an unrestricted access to the EU network for rail vehicles coming from non-EU countries. In the meanwhile, several European countries decided to establish domestic control procedures on noise emissions from rail traffic.

Today Italy has adopted European normative 2002/49/CE (25/06/2002) and 2003/613/CE with the emission of d.p.r. n. 459 of 18/11/98, for railway noise, and with the n. 447 law of 26/10/1995 (and following modification).

During recent years, in order to identify areas where noise levels exceed the legal limits, City Councils in Italy have been obliged to carry out acoustical zoning. So called "Acoustical Cleaning Plans" must be implemented in those zones identified as "hazardous". Urban areas where trains pass very close to residential buildings can belong to this class.

In this work we developed a simple mathematical model that could immediately reproduce the time history of a train transit. In addition we performed acoustical measurements in two positions at the same time, on the façade of a building placed close to Battipaglia railway.

This building was particularly interesting for different reasons. It was near enough to rails, with no obstacles in between nor reflecting surfaces in front of it. Moreover another interesting feature was its tilted position with respect to the rail line (Fig. 1). In order to minimize the background noise, we decided to perform measurements during night time. A significant amount of data has been collected. During the analysis of experimental data we realized that the numerical model could help us to reproduce and understand the noise signal shape, correlating it to different parameters, such as the emission power and the distance of the sources. A good estimation of these parameters can be achieved with a comparison between experimental and theoretical signals.

In the following paragraphs, we will present the most interesting signal shapes coming from experimental data, together with the theoretical ones that best reproduce them; we will give some physical arguments that qualitatively explain the slope of the signals and the acoustical phenomena.

EXPERIMENTAL SET UP

A set of six microphones was prepared at different heights of a building, as shown in Fig. 2. These mono and multi channels microphones belong to I precision class sound level meters, in fulfilment with art. 2 of Italian D.L. 16/03/1998.

Measurement set up is composed of 3 "SOLO" sound level meters and 2 "Harmony" ones. But only one of these was a two channel apparatus. For this reason in this first approach we present mainly results from this two channels apparatus, postponing a more detailed description, based on the six measurements array, to a future work. Time period of data taking was from 23:00 of 23/10/2006 to 07:00 of 24/10/2006.

Post processing of data have been performed by the dedicated software "***dBTrait***" from 01dB (Fig. 3), which allows us to display the time history and frequency spectrum of the signal related to the entire acquiring period or to a smaller section of it.

DATA ANALYSIS PROCEDURE

Noise produced by railway traffic is different from other kind of noise because it is characterized by single events (train transit) with different time length which produce sound levels much higher than noise related to human activity. Our railway noise study focuses on measurements of sound levels typical of single transit and on their identification procedures. In particular measurements were performed with an automatic modality in which the presence of an operator is not necessary.

During the time window related to the data acquisition period, different kind of transits occurred:

- Stopping trains
- Trains in transit
- Operating and shunting trains

The first step was the isolation of the single transit peak from background noise by watching at time history of noise signal (Fig. 3).

Once the transit has been identified, the shape of the peak shape is investigated in order to deduce information on the direction of the train, on the type of transit, on the type of train, etc. These informations are useful for the simulation of the transit with the model that we developed.

So, every peak due to the transit of a train has been isolated and analyzed in detail, taking care of two channels (two sides of the building) information and of comparison with the theoretical model. We report some of the more interesting peaks in the results paragraph.

NUMERICAL MODEL DESCRIPTION

In this paragraph we present a simple numerical model developed in the Microsoft Excel framework. This model takes into account the geometry of the environment under investigation (Fig. 4), the attenuation of noise due to geometric divergence, the vectorial nature of the signals, etc.

In particular it requires as input the acoustic power level of the sources. In this case we reduced them to a pointwise source for the locomotive and a second pointwise source for the vehicles . This last source is in charge of simulating total noise coming from the vehicles in the back side of the train, where the railcar is not anymore the principal source.

In spite of the pointwise approximation of sources, the radiation field was continuously varied from spherical to cylindrical, depending on the distances source-receptors just to take into account the relative dimensions of sources and distances.

A simulation of a random background source (calibrated on the real measured one) is also added. The calculation of a vectorial L_P has been performed with a formula with parameterized coefficients.

$$\vec{L}_P = (P - C1(t)\ Log\ (r(t)) - C2(t) + random)\ \hat{u} \tag{1}$$

where P is the emission power of the source and r is the distance between the source and the receiver and coefficients C1 and C2 vary from cylindrical to spherical values as a function of distance.

The two signals were vectorially summed (as incoherent signals) before being projected into the microphones direction. The second noise source has a variable spatial distance from the first in order to simulate the train length. In this approximation we found a first agreement with experimental data. Results are shown below, where the comparison between the experimental plots and the numerical ones is shown.

Because of the action of a virus, which destroyed the file containing the detailed information about each single transit of the trains, we had very little possibility to perform a deep quantitatively comparison between experimental and theoretical data. Nevertheless (see next paragraph) also reduced information about the transits were sufficient to regain the various shapes of the principal kind of events we had recorded. A semi-qualitatively analysis of experimental data was still interesting and could give us very useful information about the contributions of the various input parameters, involved in the description of the physical phenomena under investigation.

RESULTS AND DISCUSSION

As already said, our investigation, at the beginning, was moved by the search for the acoustical impact on the façade by the train transits during night-time. For this reason we performed measurements according to the above mentioned procedures.

Having the possibility to measure at the same time the acoustical parameters in two different positions on the building, we were interested in highlighting the peculiarities of the signals in order to spot the different contributions coming from the train structure, operating conditions and environmental situations.

As you can see from the above aerial photogrammetry (Fig. 1), from the railway station two different rail-lines depart and we call them A-line and B-line. The distances of the tracks with different numberings belonging to these two lines were also modelled. In Fig. 5 we can see, on the left, the experimental signal and on the right the theoretical one. This transit is characterized by a maximum noise level around 75 dB and a time duration of around 70 seconds.

The train transits entering the station from the A-line (from south). This figure refers to a signal shape of a freight medium length train (almost 200 m), with low velocity, transiting on one of the distant rails. The half-height and peak widths are related to the length of the train and to the numbering of the transit tracks. In particular the more extended the half-height width, the more long the train, and the more short the peak the more far the transit from receivers. In this case we find a relatively low signal level at the receivers because of a low velocity of the source. As will be clearer from what follows this is also the more symmetric experimental shape we found. That is due to the particular configuration of A-line in comparison to the B-line. As is also evident we were not able to reproduce the superposition of the two signals in the descending part of the curve. This is probably due to the non perfect modelling of the distances in the leaving part of the A-line.

In Fig. 6 we can see a different shape. This transit is characterized by a maximum noise level around 83 dB and a time duration of around 80 seconds. The signal is characterized by a flat peak with 25 seconds width. This means that the freight train had many carriages, as we simulated in the model. In order to have a maximum noise level of 83 dB, the total power emitted (noise from railcar plus noise from tracks) has to be around 125 dB. The asymmetric shape is due to the geometry of the B-line together with the tilted position of the building with respect to the railway. By inspection of the early part of this curve is evident a poor agreement between the theoretical and the experimental part. This is probably due to the presence of a bunch of trees which diffract the sound and which are not jet present in the model.
In Fig. 7 we can see a double peak signal.

This very particular shape refers to the double passage of a long freight train operating in the sidings area in front of the microphones. The train operating up and down the track passes just twice in front of the two receivers producing this double peak structure. As it can be seen in Fig. 1 the operating and shunting area is just ahead of the building where measurements are performed. In our model this shape is regained just setting a negative value for the acceleration of the sources. In the experimental figure we see in the first part the point line up and the dashed one down, that means the bulk of the train is at left with respect to the receivers. In addition the signal has a positive derivative, this means that the train is approaching the building. Immediately after we see a situation in which the train is on the right of the building and approaching it.

In Fig. 8 we find a pattern from a stopping train. This signal is clearly related to a stopping train. The very long slope is due to the breaking phase, which is very noisy, while the sudden fall of the signal represents the final stop of the train.

CONCLUSION

A significant amount of acoustical experimental data regarding the movements of trains in a little railway station during night time was presented in this paper. The measurements were performed by simultaneously recording six signals in two positions per each of the three floors of the building. But, in this work, we limited our analysis to the lower two channels of the first floor. This approach is interesting because allows us to simulate some sort of big acoustical acquisition system (which could reminds the position of human ears) and let us to discriminate various acoustical parameters such as directions, distances, emission powers, etc.

As for the numerical model we wrote a simple Excel program in which the physics of the phenomenon is described by the vectorial nature of the sound coming from different sources, their vectorial composition as incoherent signals and with final projection into the microphones direction. By this means we were able to regain the shapes of the freight trains passing during that night, in various situations: passing, operating and shunting, breaking and stopping.

At the moment the signal shape of passengers trains is not discussed because it requires a more accurate description of the trackage configuration.

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[5] Google Earth Copyright

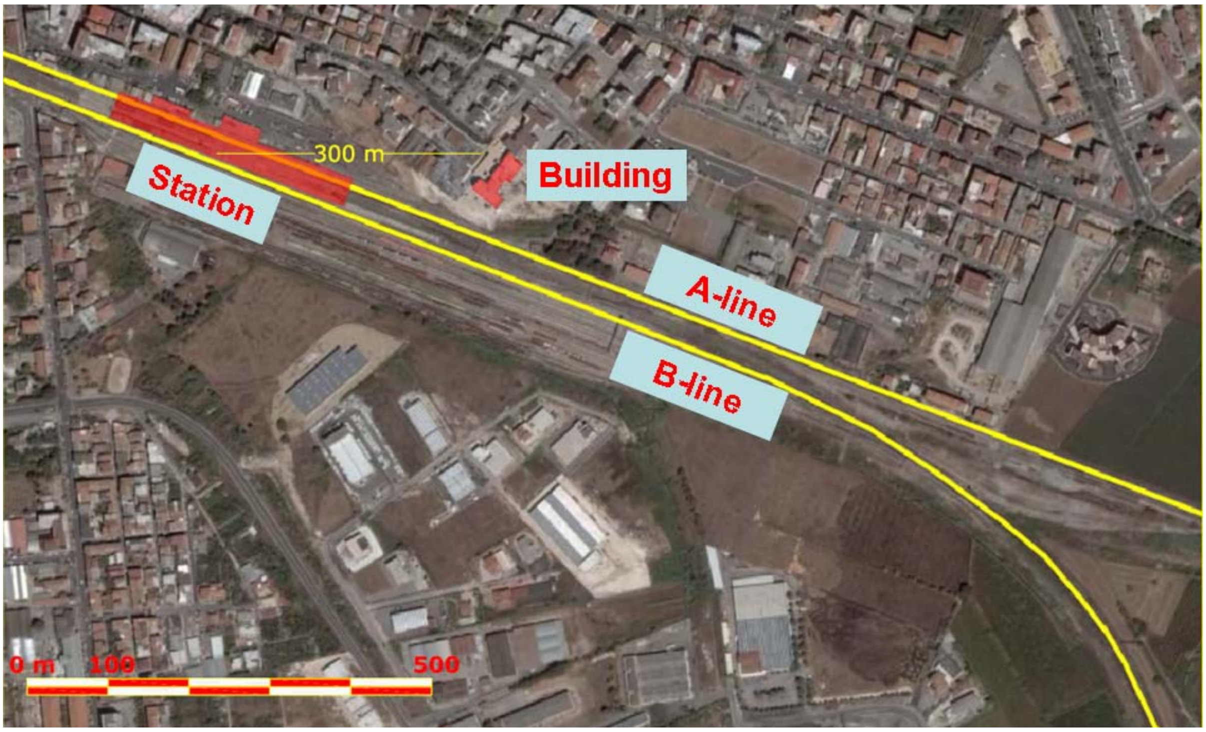

Fig.1. Aerial photogrammetry of area under investigation. [5]

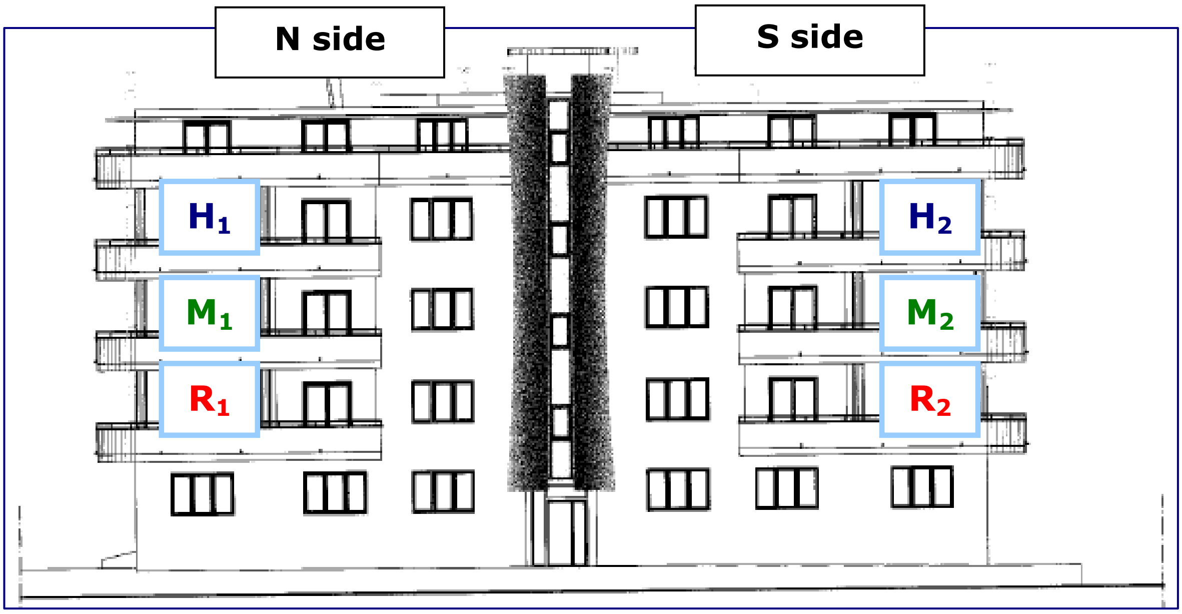

Fig. 2. Schematic view of experimental set up.

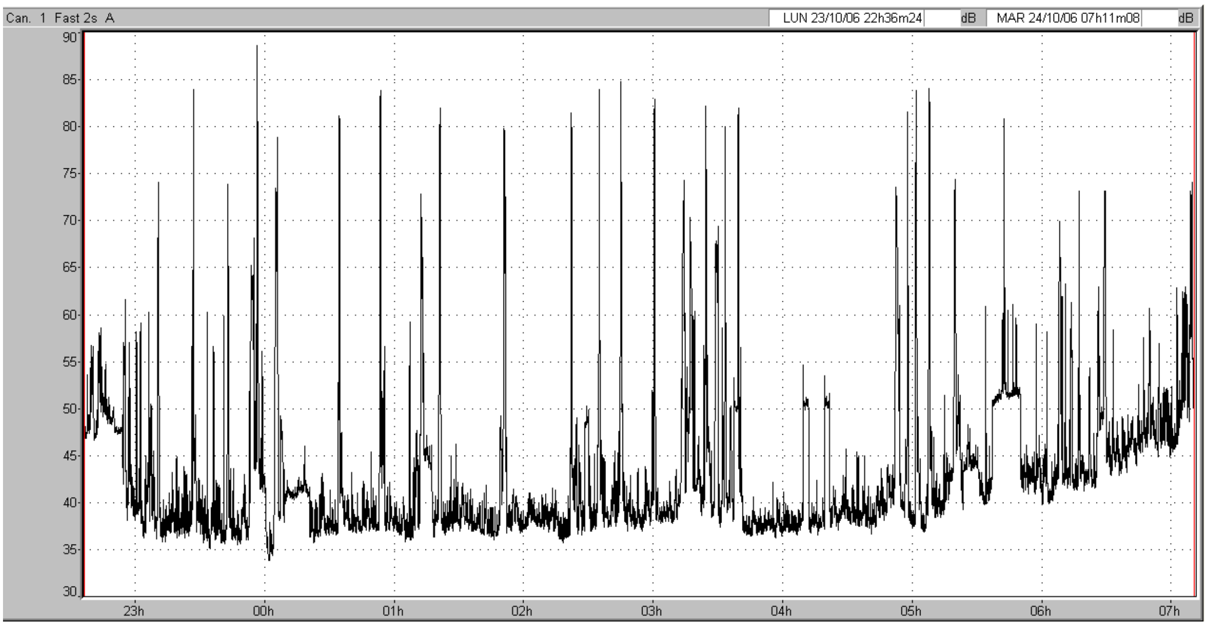

Fig. 3. Time history (L_{eqA} [dB] vs *t* [s]) of whole acquisition period with ***dBTrait*** software. Channel 1 is plotted.

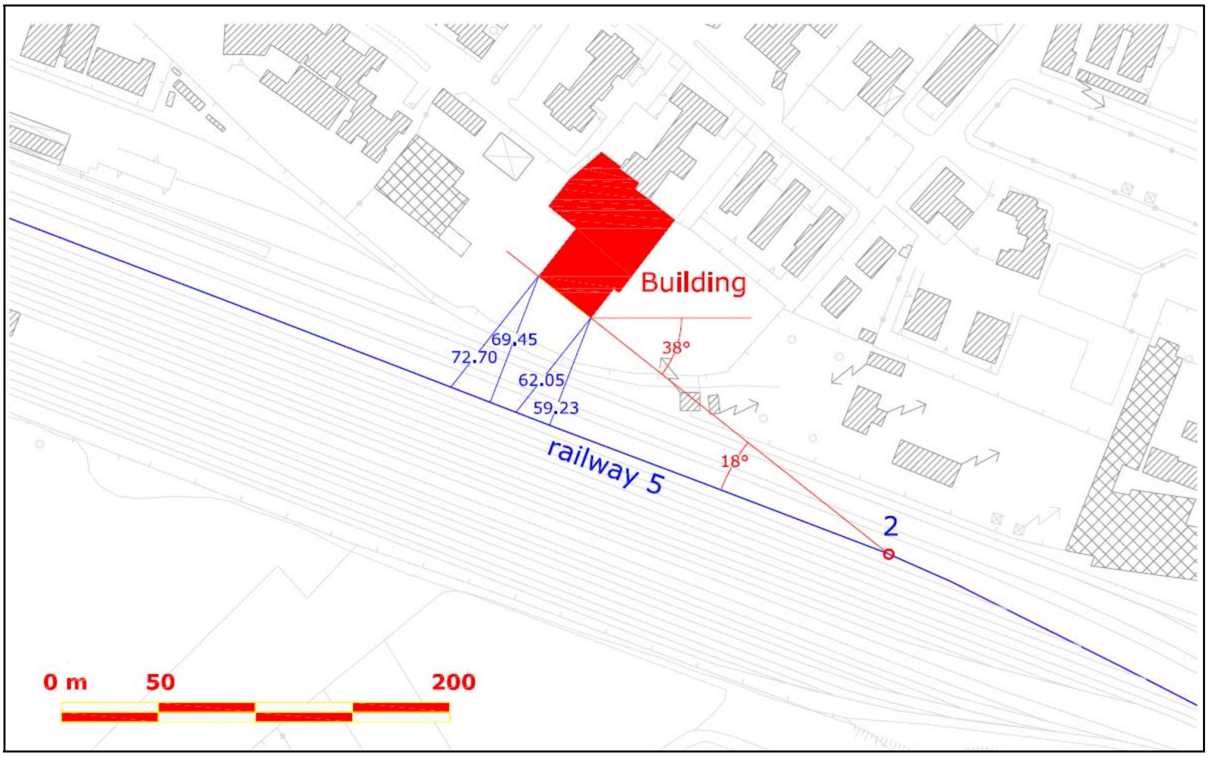

Fig. 4. Layout of experimental area.

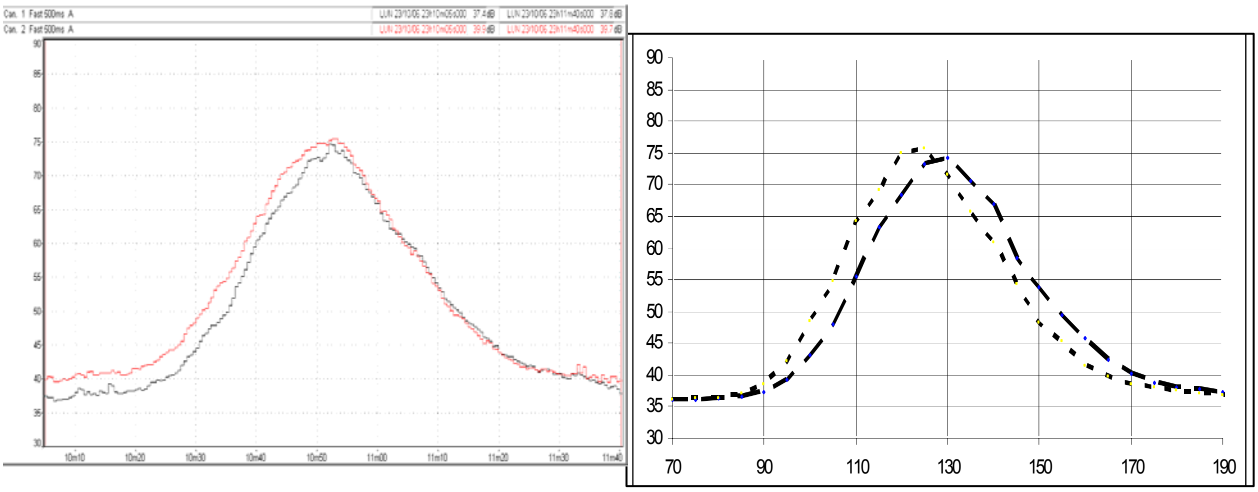

Fig. 5. Comparison between experimental (left) and theoretical (right) signals. On the *x* axis the time [s] is plotted, while the L_{eqA} [dB] is reported on the *y* axis.

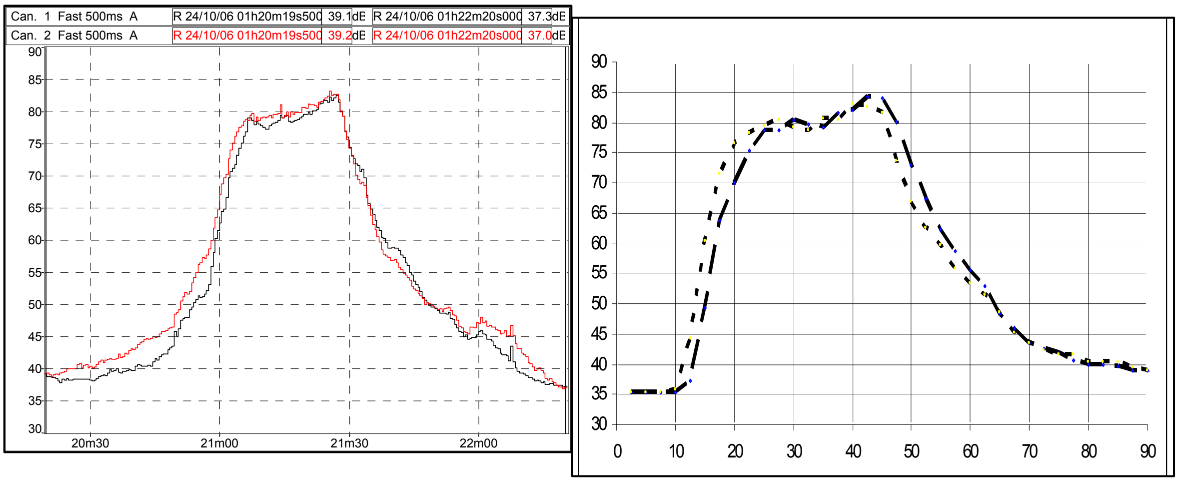

Fig. 6. Comparison between experimental (left) and theoretical (right) signals. On the *x* axis the time [s] is plotted, while the L_{eqA} [dB] is reported on the *y* axis.

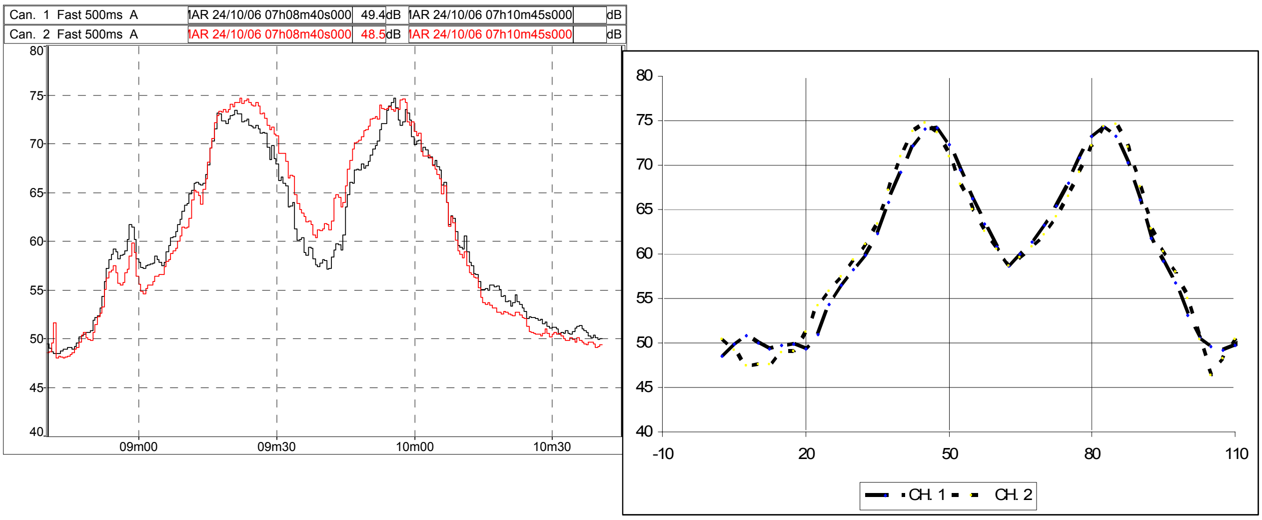

Fig.7. Comparison between experimental (left) and theoretical (right) signals. On the *x* axis the time [s] is plotted, while the L_{eqA} [dB] is reported on the *y* axis.

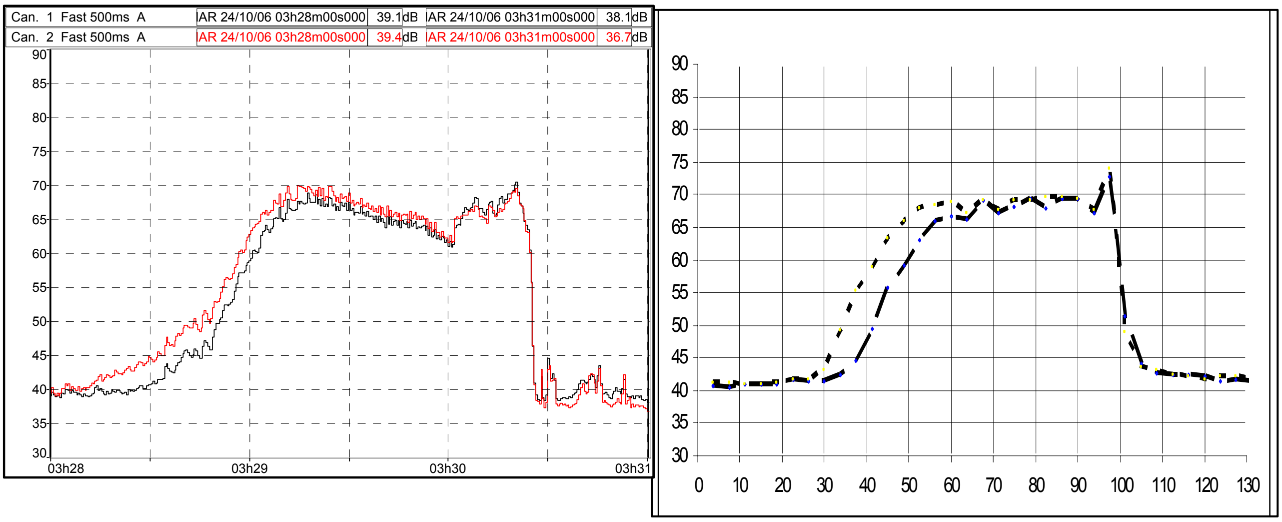

Fig. 8. Comparison between experimental (left) and theoretical (right) signals. On the *x* axis time [s] is plotted, while the L_{eqA} [dB] is reported on the *y* axis.