Military Technical College
Kobry El-Kobbah,
Cairo, Egypt.

13th International Conference
on Applied Mechanics and
Mechanical Engineering.

MEASUREMENTS OF HIGH SPEED TRAIN NOISE DETECTED AT A RELEVANT DISTANCE AND A SIMPLE NUMERICAL MODEL.

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ABSTRACT

In this paper an experimental activity regarding the detection of noise produced by a high velocity train along a "almost" straight railway, and a semi-quantitative theoretical model which gives the shape of trains noise in that running conditions, are described. During this investigation the comparison between software predictions and experimental measurements was focused. At the present stage of our study we are starting with the theoretical reproduction of the time history of the phenomenon. In a previous paper we reported about the same goal referred to low velocity trains with very different operating conditions. So in this work we try to underline differences and similarities.

The experimental measurements procedure is based on the detection of the sound level outside a building placed in an interesting position with respect to the rail line. It is some three hundred meters far and in a position from which one can observe more than three kilometres of railway. Measurements were performed by a first class Measuring System.

KEY WORDS

High speed train, noise detection, simulation model, time history

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INTRODUCTION

The train industry has recently undergone a flourishing period of improvement and innovation, especially in the high-speed vehicle technology, that is due to the growing necessity of an efficient transport system in order to compete with airplane and automobile vehicles. In the last 25 years, railroad engineering research has led to vehicles travelling at speeds as high as 300 km/h (Mach number M=0.24) and more, especially in densely populated areas, such as Western Europe, Japan and South Korea. Technological advancements have grown together with engineering problems such as the increment of aerodynamic drag ([1], [2], [3], [4]), the stability of the vehicle and the growth of noise pollution.

Generally speaking, railway noise depends primarily on the speed of the train, but variations are present depending upon the type of engine, wagons, and rails and their foundations, as well as the roughness of wheels and rails. Small radius curves in the track, such as may occur in special areas, can lead to very high levels of high-frequency sound (referred to as wheel squeal). Noise can be generated in stations because of running engines, whistles and loudspeakers, and in marshalling yards because of shunting operations.

The introduction of high-speed trains has created special noise problems with sudden, but not impulsive, rises in noise. At speeds greater than 250 km/h, the proportion of high-frequency sound energy increases and the sound can be perceived as similar to that of overflying jet aircraft. Special problems can arise in areas close to tunnels, in valleys or in areas where the ground conditions help in generating vibrations. The long-distance propagation of noise from high-speed trains will constitute a problem in the future if environment-friendly railway systems are not expanded. [5]

In this paper we present acoustical measurements performed outside a building placed (around 300 m) in front of an italian high-speed railway as shown in Fig. 1. The position of the receiver is quite interesting because of the absence of obstacles between the railway and the building and because of the small valley in which the transits happen.
The particular environmental conditions are discussed, and the geometry of the area, together with the type of trains running, is modelled by an improvement of the numerical method presented in this same conference [6].

This numerical method is based on the modelling of the transit with different parameters such as emission power, train length, velocity, distance, etc. In the data processing phase, by comparisons between experimental and numerical signals, we can find out the values of parameters that best reproduce the noise signal shape and deduce physical arguments on the phenomena.

EXPERIMENTAL SET UP

The building under investigation is placed at a distance of about 300 m from the railway. Its position is higher with respect to the railway. The “acoustic visual angle” is very big and consequently the corresponding rail line is around three kilometre long.
The rail line presents three different conditions (Fig. 2): starting from the North side (on the left), we find a viaduct, followed by an embankment and again a viaduct.

A set of three microphones was prepared, one outside the building under investigation, and two inside of it, as shown in Fig. 3. These microphones belong to a first precision class sound level meters that are part of a complete acoustical system, in fulfilment with art. 2 of Italian D.L. 16/03/1998.

In this first phase we present results only from the outside microphone, postponing a more detailed description, based on the inside apparatus, to a future work. Time period of data taking was from 08:55 of 30/09/2006 to 13:20 of 30/09/2006. Post processing of data have been performed with the dedicated software "***dBTrait***" from 01dB (Fig. 4), 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

As can be seen from Fig. 4, noise produced by high-speed train traffic is characterized by single transits, corresponding to signals levels, easily identifiable because much higher than background noise.

Our study focuses on the measurements of noise levels related to single transits and on their comparison with the numerical predictions. In the area under investigation, a straight railway line exists. These tracks are dedicated to high velocity trains. As a consequence we measure signals coming from different trains having strong similarities when compared each other.

During the time window related to the data acquisition period, eight transits occurred. Data analysis procedure is similar to that described in [6]. The first step was the isolation of the single transit peak from background noise by watching at time history of the noise signal. Once the transit has been identified, the signal is centered in the peak and is cut 45 seconds on the left and on the right. So we can appreciate the slope of the signal, together with its overall length.

These information are then implemented in the numerical model for the simulation of the transit. In the results paragraph some of the more interesting comparisons are reported.

NUMERICAL MODEL DESCRIPTION

Now we present the simple numerical model developed in the Microsoft Excel framework used for calculating the signal prediction. This model evaluates the geometric divergence of sound, taking into account its vectorial nature. Geometry of the area under investigation is simulated mainly in a two dimensions approximation. Third dimension is considered in an indirect way: we inferred it from Google's maps.

The model requires as input the acoustic power level of the sources. Two pointwise sources were simulated, one for the locomotive and the other for the vehicles. This second source is in charge of simulating total noise coming from the vehicles in the back side of the train, so that, simply by rising or lowering the distance between the two sources, we can simulate different train lengths. But even if a pointwise approximation of sources is assumed, the radiation field was continuously varied from spherical to

cylindrical by varying the coefficients C1 and C2 in the formula (1). This allows us to find a good compromise between the pointwise and the linear source approximation.
The vectorial sound level L_p was calculated for both sources with the following parameterized coefficients formula:

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

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 resulting signals for the two sources were then vectorially summed (as incoherent signals), before being projected on the microphone direction. A random background noise source was simulated and added in the plots, calibrating its level on the real measured one. The results coming from the described model have been compared to experimental data. A good agreement is achieved with reasonable values for the formula parameters.

RESULTS AND DISCUSSION

As we explained before, this investigation was moved by the interesting conditions of experimental area, in term of geometry, environmental features, building position, etc. For these reasons we performed measurements according to the above procedures.

The reconstruction of the signals shape with our model was interesting in order to separate and understand different contributions coming from train length, speed and environmental conditions. In this paragraph we show the signals related to the eight transits occurred during data taking, together with some numerical simulations.

As you can see from the above aerial photogrammetry (Fig. 1, Fig. 2), the building is placed in front of the railway line, having on its left the North direction and on its right the South one.

In Fig. 5 and Fig. 6 we show respectively four transits in South direction and four towards North. The alignment is obtained by centring the four peaks in 1 minute and 30 seconds plot interval. This allows an easy comparison, together with the possibility of reconstruct similar features of the transits.

It is easy to see that the signals are very similar, with many ripples due to environmental and background noise. The signal shape of each transit is characterized by around 40 seconds length and it is not perfectly symmetric with respect to the maximum level. Comparing North-South transits, it is important to notice that the signal slope has a little variation depending on the direction of the train. Trains running in North direction have a slow rise but a relatively quick fall, while in South direction this is inverted. This is due to the geometry of the area.

In Fig. 7 we report the train path subdivided in three regions: the green (North, on the left), the red (in the middle, just in front of the receiver) and the blue (South, on the right). In this latter region we are also presenting a train (an in scale white segment with a red point representing the locomotive) heading towards South.

On the same image the time history of the signal produced by the white train is superimposed. So we have a graphical correspondence between the average train position and the related signal value. In the fourth ten-seconds region we measure an increased signal with respect to the immediately previous values. This is due to the bent of the railway. This is a very interesting phenomenon we think have theoretically explained and that will be subject of a future work (*).

In Fig. 8 we redraw fig 7 as it appears in Google Earth representation. As is known by this means is also possible to have a coarse estimation of the local altitude. So we see that the area on the right of the receiver position is lower than the receiver itself, whereas the little hill present on the left is a natural screen which explains the reduction the green-coloured signal length.

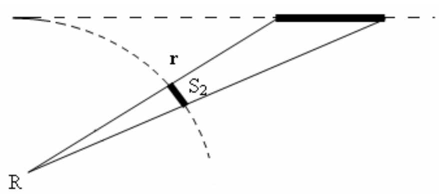
Regarding the transit occurred at 08:57 (see Fig. 6), one can observe that it is characterized by a peak level of a few decibels more than the others. This is probably due to the humidity of air, in fact higher values of humidity correspond to higher values of density of air. This leads to a higher transmitting capability, which corresponds to a little rise in the maximum value of noise signal. This dependence is not yet simulated in our model, so we postpone this kind of studies to future works and measurements.

Let's show now the comparison between some of these signals and the numerical predictions. In particular in Fig. 9 and in Fig. 10 we can see, on the left the experimental signal and on the right the theoretical one, related respectively to a transit in South direction and in North one. In order to obtain a good agreement between the two plots, we had to properly set values of the parameters of the numerical model. In particular, the emission power of the locomotive, which is in charge of simulating the locomotive noise, has been set to 125 dB. The relative distance between sources has been set to the length of the train, i.e. 350 m. This value, as already said, is due to the length of the train. In fact the high velocity Italian train is composed by twelve vehicles, plus two locomotives, one at the beginning and one at the end of the train.

CONCLUSION

This study focused on the characterization of acoustic noise produced by high speed trains running on a high velocity Italian rail line. In this paper some acoustical experimental data concerning high speed train transits were presented. A far position of the receiver was chosen, in order to study and characterize the far acoustical field in typical environmental conditions. Geometry of the path, relative heights of the sources and receiver were taken into account when writing a simple numerical model. Direction of train doesn't affect significantly the maximum level of signals since the distance between tracks (around 5m) is negligible with respect to receiver-source distance.

(*) J.Q. demonstrated that the signal received in R from an infinitesimal linear source is equivalent to that generate from a curved source (arc of a circumference) if they have the following relative position:



In contrast to the case presented in [6] which deals with low velocity regime, the transits reported in this paper are characterized by quite equivalent sources, because the trains are exactly the same and the velocities are almost the same. Although the study is still incomplete and lacking of relevant theoretical corrections (such as the evaluation of the contribution from an acoustical barrier present in a part of the line, the bending of the tracks, the attenuation from the air, etc) the comparison from the experimental data and theoretical results are encouraging enough to push us to continue.

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[7] Google Earth Copyright.

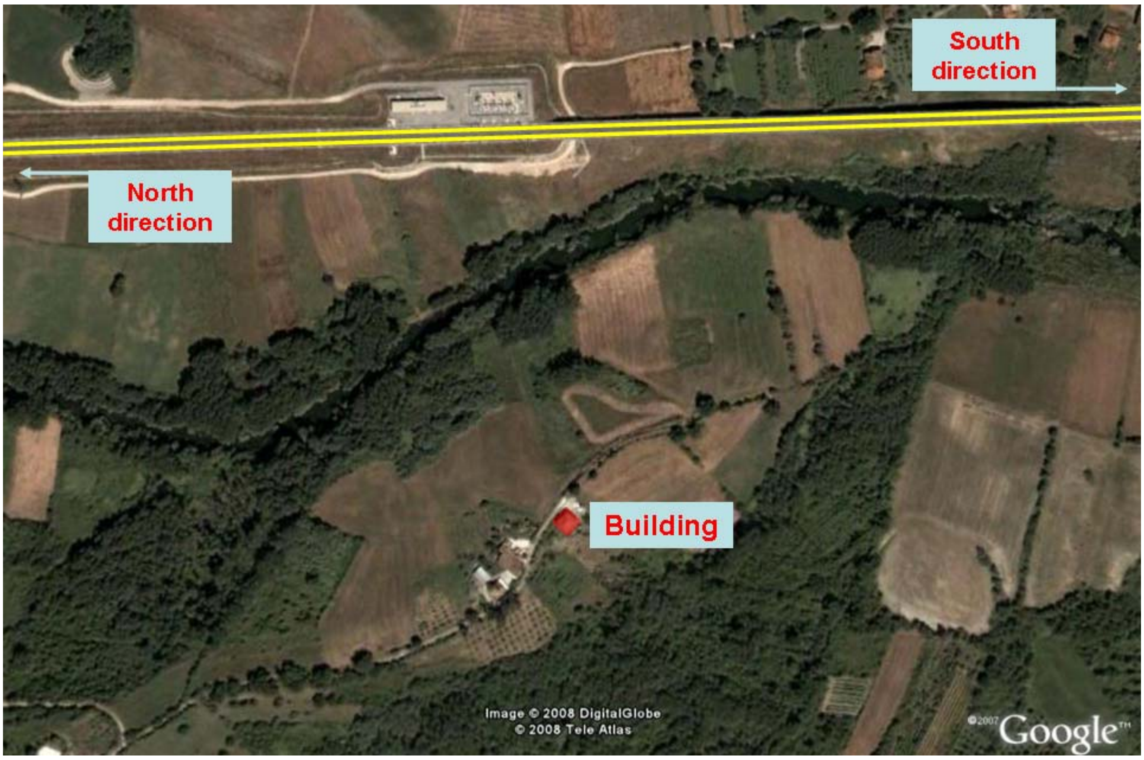

Fig.1. Aerial photogrammetry of area under investigation. [7]

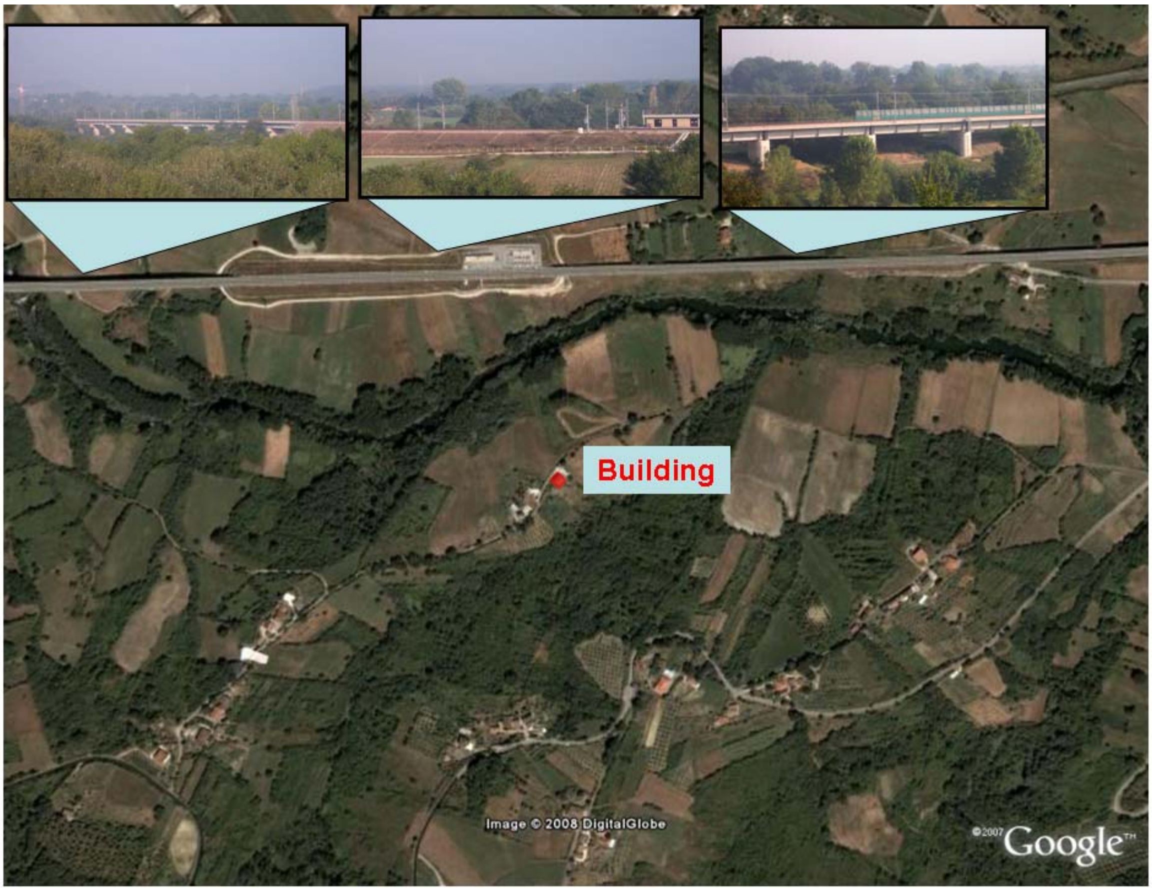

Fig.2. Pictures of area under investigation. Starting from North direction, on the left the first viaduct, on the center the embankment in front of the building and on the right the second viaduct with the acoustical barrier.

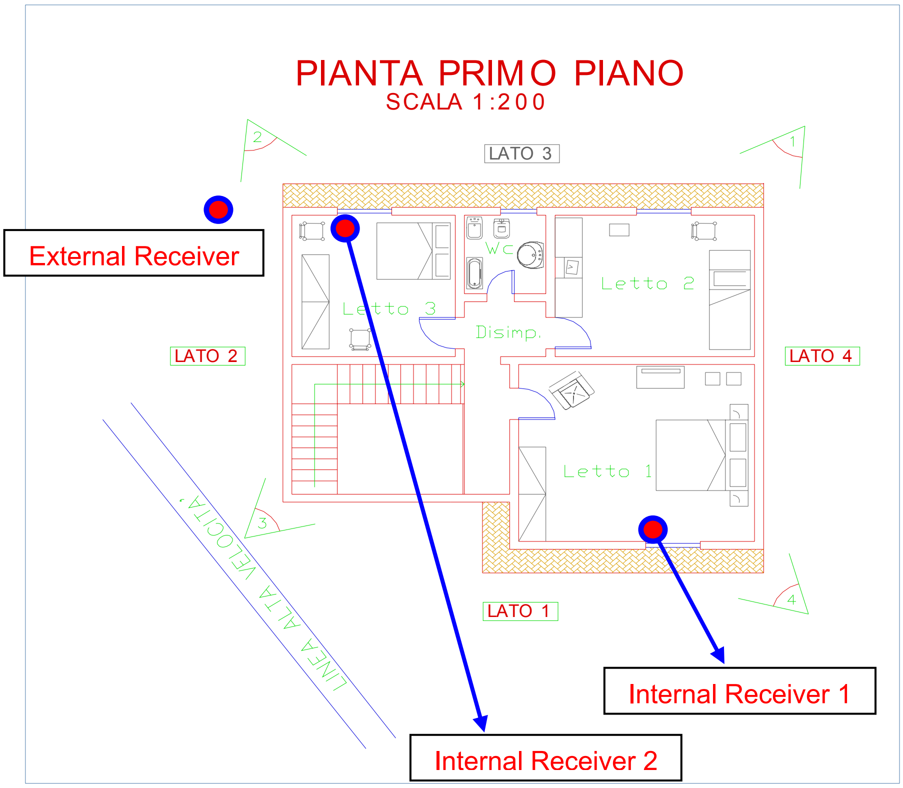

Fig. 3. Schematic view of experimental set up in the building.

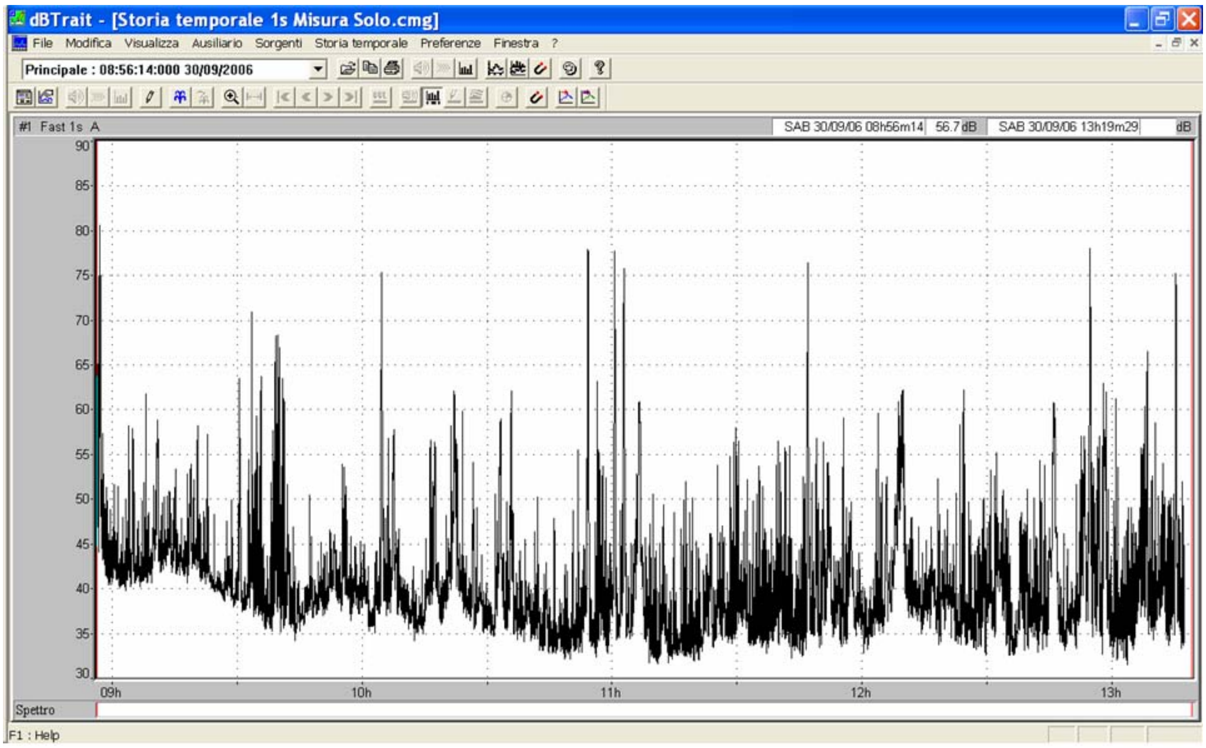

Fig. 4. Time history of whole acquisition period with ***dBTrait*** software.
Noise level [dB] versus time [s] is plotted.

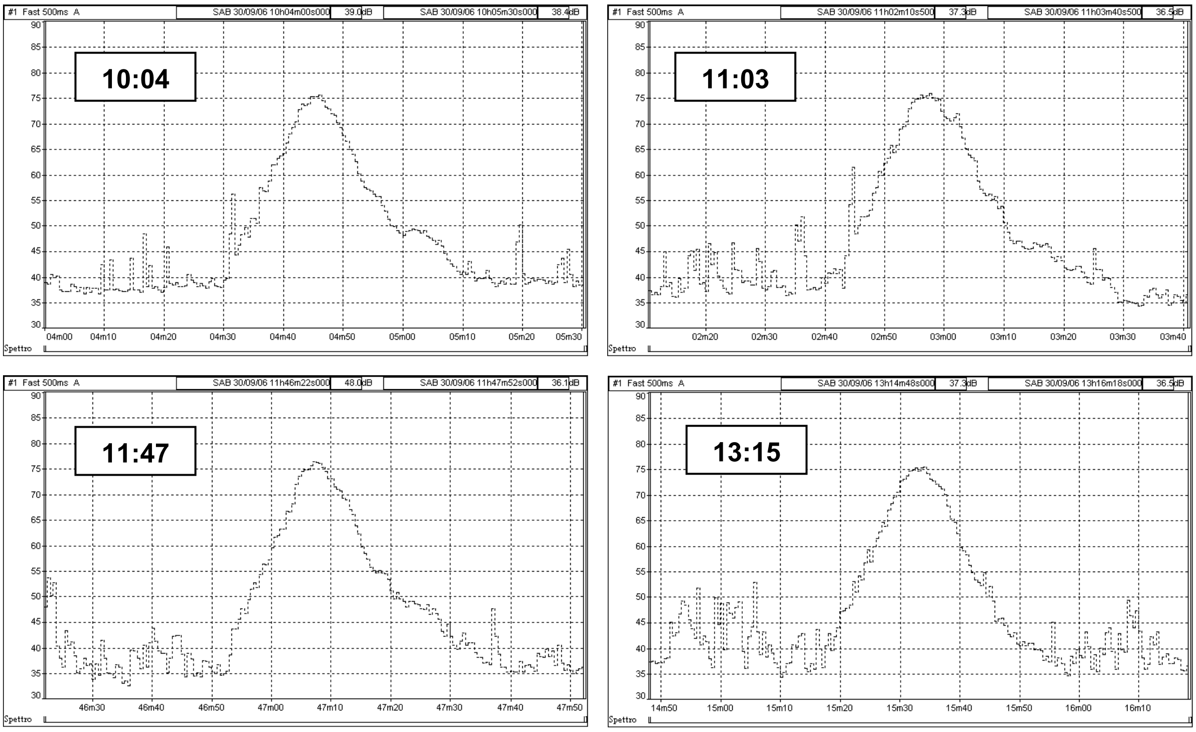

Fig. 5: signals related to four transits in South direction.
Noise level [dB] versus time [s] is plotted.

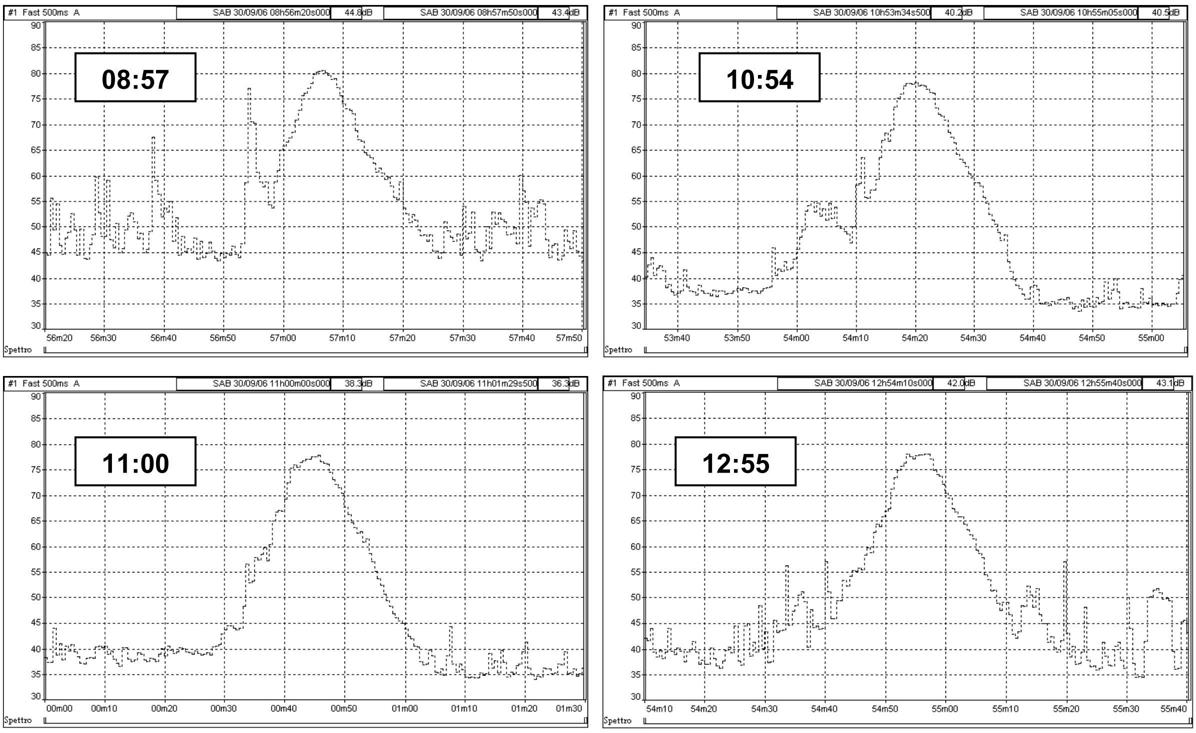

Fig. 6: signals related to four transits in North direction.
Noise level [dB] versus time [s] is plotted.

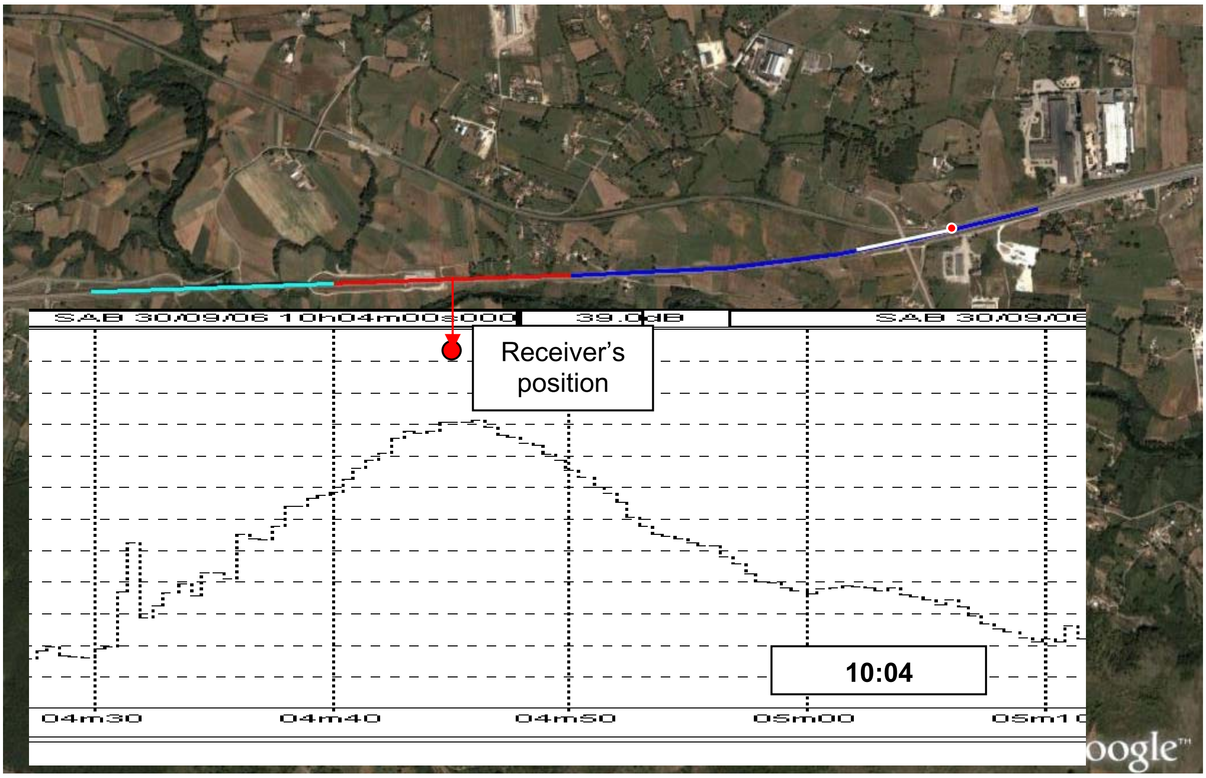

Fig. 7: superimposition of train transit signal (Fig. 5a) and rail line.

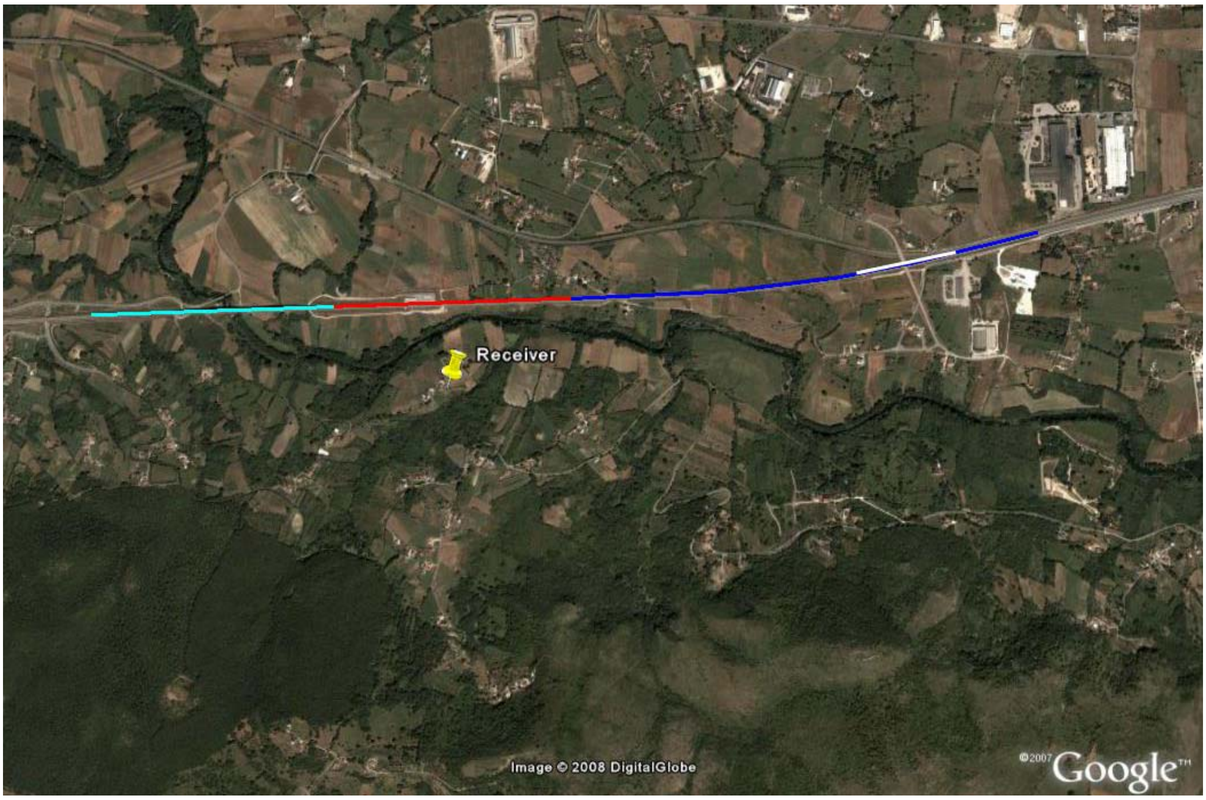

Fig. 8: train transit. Different colours refer to the raising, the peak and the lowering part of the signal (see also Fig. 7).

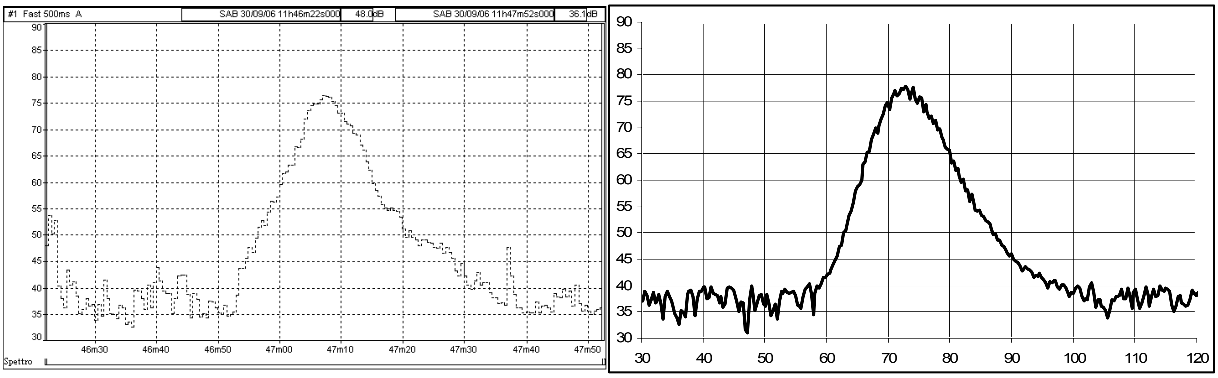

Fig. 9: Comparison between experimental (on the left) and theoretical (on the right) signals in South direction (10 s / div). Noise level [dB] versus time [s] is plotted.

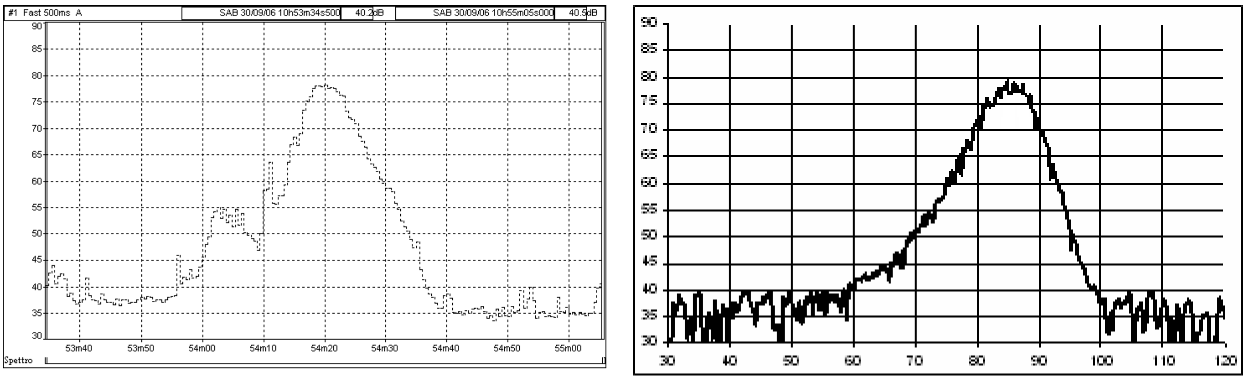

Fig. 10: Comparison between experimental (on the left) and theoretical (on the right) signals in North direction (10 s / div). Noise level [dB] versus time [s] is plotted.