Application of a Predictive Acoustical Software for Modelling Low Speed Train Noise in an Urban Environment

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Abstract: - In this work the noise impact of train transits, in the framework of low velocity regimes, is considered, especially in proximity of a railway station. The environmental impact observed in the neighbourhood of the station is highlighted, considering the Sound Pressure Level of noise coming from train transits and the equivalent Level evaluated during the full day operating time of the railway. In particular we performed a comparison between the experimental results obtained from noise measurements detected on a building façade close to a railway station at night time, and the algorithmic simulations obtained by means of a predictive software.

Regarding the simulation activity, train transits and the related auxiliary noise sources have been realistically modelled by considering different types of trains and of running conditions, making the simulation run on a 24 hours time interval. A relevant aspect of this study is the representation of the results. Different plots are presented, with particular emphasis to contour plot maps.

Key-Words: - Noise, Railway, Simulation Model, Predictive Software, Time History, 3D Map.

1 Introduction

The growing of a significant attention with respect to problems related to environmental pollution induced in the last years enormous efforts in order to develop studies capable to face such a relevant problem. A very important task in this sense is represented by the development of suitable techniques in order to analyze problems related to noise pollution. 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.

Nowadays, 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. On the other side 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.

In the framework of European policy regarding noise pollution, it is strongly suggested to work on the harmonization of data analysis methods. The aim is to draw up "noise maps" and define threshold values which can be employed as general schemes in order to treat the issue both on the urban and extra-urban environments.

In this paper we focus on a particular branch of the general noise problem, i.e. railway noise. Concerning railways, 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.

In this frame, 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). After the assumption of such a definite legislation, Italian City Councils stated that areas with noise levels exceeding legal limits should have to be identified, in order to develop necessary actions able to keep people safe from such a dangerous risk situation. The net effect was the development of acoustical zoning and of "Acoustical Cleaning Plans" in those zones identified as "hazardous". Urban areas where trains pass very close to residential buildings can belong to this class and represent, as a matter of fact, very significant areas to study.

In this work we exploit facilities implemented in predictive software in order to characterize an area placed in the neighbourhood of the railway station of a town in South Italy, i.e. Battipaglia. This area has been already investigated in a previous paper [4] by means of experimental measurements and with the development of a simple mathematical model that could immediately reproduce the time history of a train transit. It has to be remarked that the simulation software provides an equivalent level related to the whole preferred time of integration. This achievement is quite more general with respect to the measurement of the single transit and furnishes a description of how the entire region is influenced by the railways station activity. Since data in [4] have been collected with detectors framed on the façade of a building placed close to Battipaglia railway, in the simulation process we developed a tool able to measure the equivalent level induced on the correspondent building façade during the entire time of measurements, in such a way to check the predicted emission with the experimental measurements. The considered building is placed in a position which allows a direct detection of train transits acoustic emission and makes easier to study the phenomenon without incurring in spurious effects due to second order reflections and so on. We developed a predictive framework by considering an average number of train transits for each class of train, based on the timetable released by the station under investigation. The model we developed is characterized by three simulated railway lines, displaced at 14m distance from each other, in order to mimic the entire set of railway lines with the relative exchanges. This choice has been made in order to simplify the simulation model and, thanks to its schematic approach, it renders our description easy to implement in a software framework. In fact, a great number of sources and of noise emitters can heavily affect calculation time, without necessarily improving simulation results. In order to validate our approach, we have checked this assumption with a test run in which the simulation model has been configured in a more general way which contemplates the exact number of railway lines. We obtained that a smaller number of railway lines can be sufficient to describe the acoustical behaviour of the area, since the relative distance between contiguous tracks cannot be discriminated into the averaged acoustic signal approaching the detector.

2 Experimental set up

The area under investigation represents a very interesting place since its position allows to investigate noise emission coming from station and train transits without the need of introducing other sources.

From the experimental point of view a set of six microphones was prepared at different heights of the building, as shown in Fig. 3. 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. We refer to data collected by the two channels Harmony apparatus placed at first floor of the building (see Fig. 2). Data taking is referred to a time period ranging from 23:00 of 23/10/2006 to 07:00 of 24/10/2006.

Post processing of data has been performed with the dedicated software "*dBTrait*" from 01dB (Fig. 3). A detailed description of the experimental set up and of all the other peculiarities of data analysis can be found in [4].

Fig.1. Aerial photogrammetry of area under investigation. ©2007 Google.

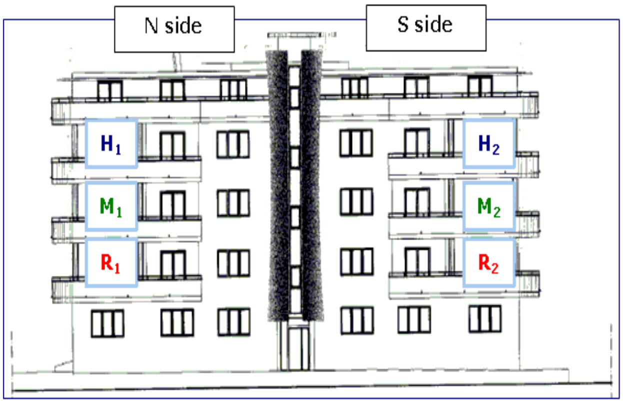


Fig. 2. Schematic view of experimental set up on the building façade.

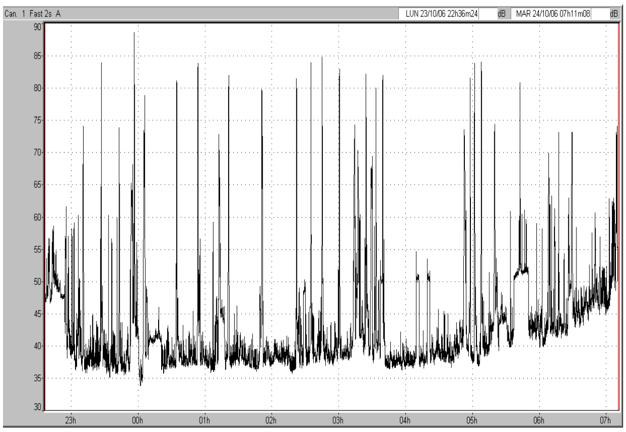


Fig. 3. Time history (L_{FastA} [dBA] vs t [s]) of whole acquisition period with ***dBTrait***

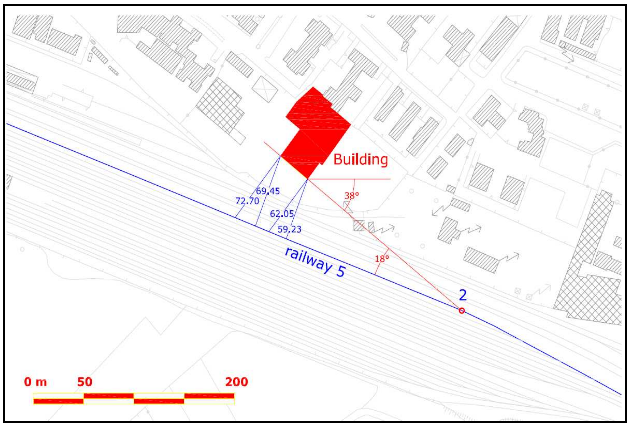


Fig. 4. Layout of experimental area.

3 CadnaA software prediction: the model

The predictive simulation is performed by means of the software CadnaA-Mitrha by Datakustik. In order to model train transits we have exploited its built-in package related to train acoustic emission. The emission level for railways has been calculated according to SRM II (Reken-en Meetvoorschriften Railverkeerslawaai '96), which takes into account the Netherlands national computation method for railway noise emission published in [5]. This protocol is recommended by EU commission guidelines as indicated in 2002/49/CE.

The software is based both on "Angle Scanning" and on the inverse "ray-tracing" principle: area under analysis is divided in many small surfaces in which a receiver is placed at a variable height, so that to build a determined calculation grid. Each receiver releases many rays with a full angle coverage (omni directive) and these rays, eventually after many reflections, intercept the noise source. The path length of the single ray describes the attenuation of the sound wave coming from a certain noise emitter.

Since we are considering an urban environment, i.e. not industrial, train transits are the main noise source in the area and has to be mixed to the background noise coming from human activities. We have performed calculations considering different schemes and different configurations for train transits rate, emission power, position, etc.. Furthermore, by means of the CadnaA software, we have developed different codes able to mimic the whole setting phenomenology considering geometrical approximations of railway effects. In such a case we have introduced a linear source mimicking trains transit emitting during the simulation time with a certain acoustic power according with the relative train prescriptions. Exploiting the timetable of Battipaglia station we have endowed different rail tracks with a certain amount of train transits considering that it was even known from station indications what were the line relative to each transit. As we said in the introduction basic model we considered three rail lines which collapse one into the other so that to get one outgoing and one ingoing tracks outside the station.

In [4], the experimental setup was built in order to perform measurements during night time so that to minimize the background noise. Actually, in our simulation we considered the whole day operation period, and we have opportunely calculated the "day" sound level (L_d) and the "night" one (L_n), i.e. the equivalent level integrated respectively during day time (from 6:00 to 21:00) and night time (from 21:00 to 06:00) according to the usual definition:

$$L_{eq} = 10Log\left[\frac{1}{T}\int_0^T 10^{\frac{Lp}{10}}\,dt\right], \qquad (1)$$

where T is the considered time, L_p represents the pressure level of the acoustic signal.

In order to calculate our L_{den} output, i.e. equivalent sound level during whole day (day, evening and night time), one has to give in input to the calculation code, the exact train typology, the number of transits and the features of the tracks. The integration time along which the equivalent level is calculated represents the time-interval submitted to the simulation process.

The whole simulation has been obtained considering a 24-hours working time of Battipaglia station. As a matter of fact we took into account 50 (35 Day, 15 Night) freight trains moving on the outer track (the more external with respect to the detection area) and finally moving away on the middle line, 20 regional trains (10 Day, 10 Night), 10 high velocity trains and 10 intercity moving in the middle track, and 5 high velocity trains running on the internal path (the closest to the detection building). The trains moving on the inner path will converge to the middle track in the case of the high velocity trains and will continue on the inner rail track in the case of the regional ones. We have even considered the rate of trains breaking when approaching the station. We consider that respectively the 80% of regional trains of the inner path and the 70% of regional trains moving along the inner path, stop in the station. We even consider that the 30% of freight trains stops. Line A and line B of Fig.1 represent the external lines of our model and have been mimicked with the external tracks of Fig. 5.

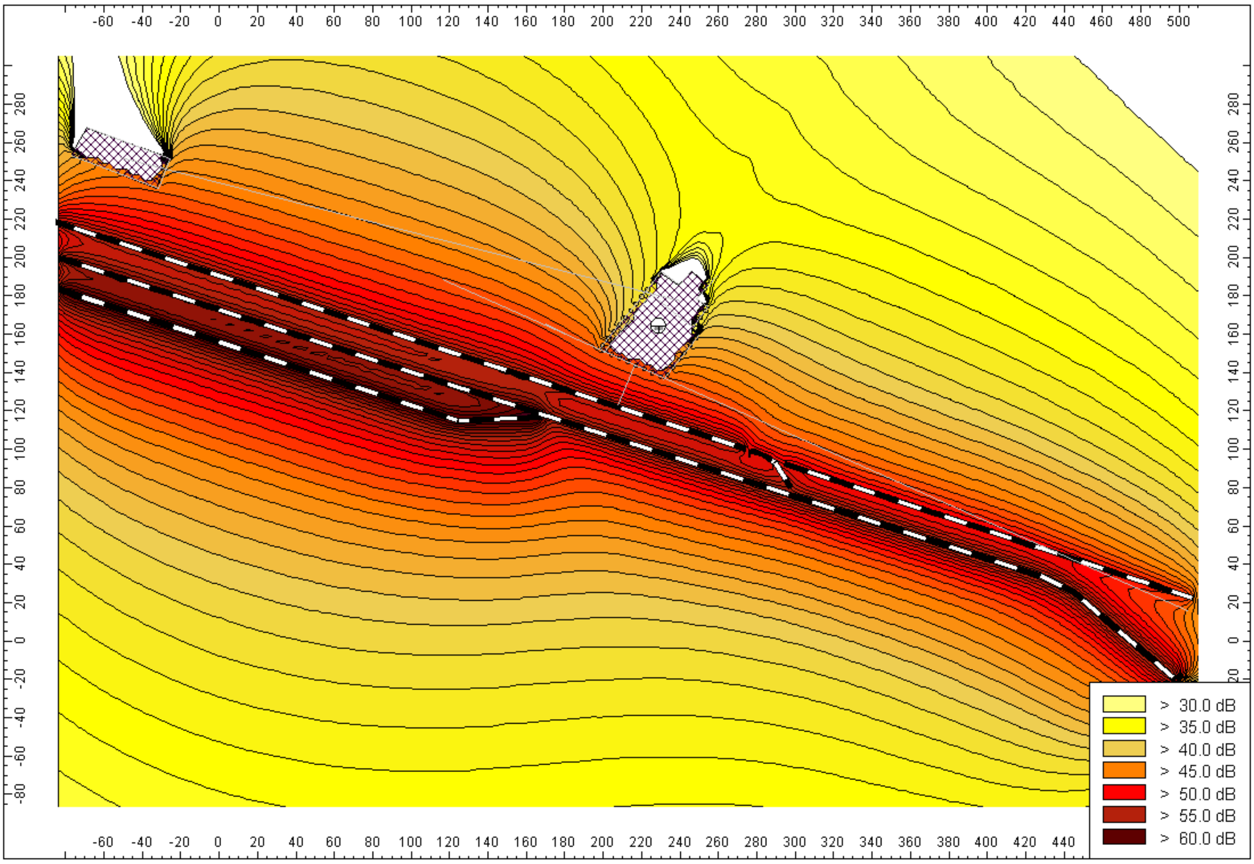
The receiver grid was constructed in such a way to have detectors placed at the middle of a 9m^2 square at the height of 4 meters each, we have not considered meteorological corrections at this level.

After the integration time we obtained a map of acoustic emission developed in term of the L_{den}. In particular we concentrate on the L_d and L_n in order to discuss our analysis. In fact the noise impact of the different sources present in the area under investigation is described by means of contour plots describing the same level of emission. We have even performed a 3D analysis in order to directly check the experimental result since, as said, the measurement was performed on the façade of the detection building. In other words we proposed a 3D contour plot insisting on the building which accounts for the effective noise experienced by an observer framed into the observation building.

4 Results and discussion

By considering the algorithm we outlined above, which is based on an analytic check of train transit in the region under study, we can develop some contour maps regarding the L_{den} which can be compared with the experimental results obtained during the data taking [4]. In this picture we display the L_d and L_n level generated in the region of the station point, up to the detection building and it is evident that the most of the signal is in the railway region. Fig. 5 suggests an averaged value of the acoustic emission at the detector which is around 45dBA both in the L_d and the L_n case. These pictures which seem quite similar, in reality, show some differences in the regions closest to the rail paths.

In addition, in order to have a clearer sketch of what are the effects induced by the train transit on the building present in the detection area, we have generated a 3D map of the acoustic level emission referred to the L_n rate. This approach allows to have a more general view of the noise impact considering both the experimental setting and the environment substructures.



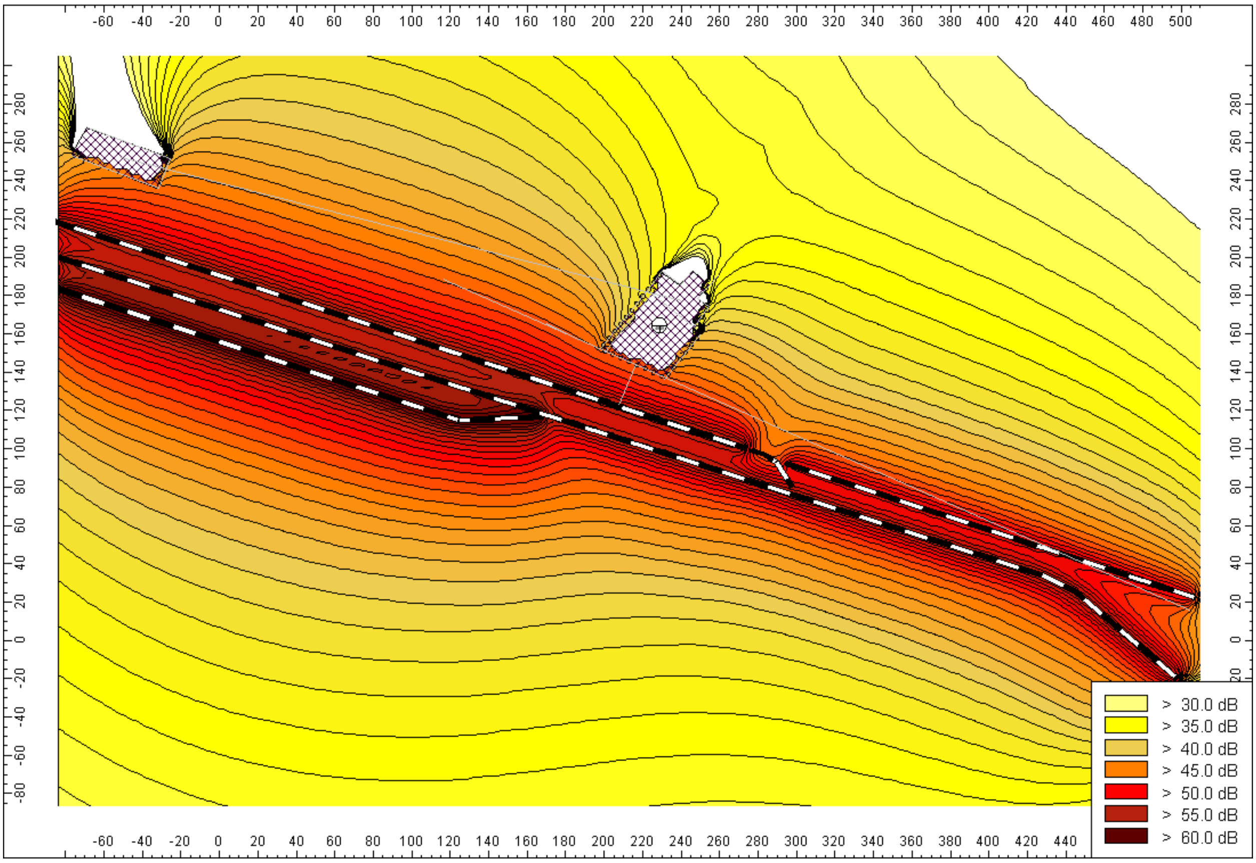


Fig. 5 A contour plot map of L_d (up) and L_n (down) of the acoustic emission due to the railway system working in the neighbour of Battipaglia station as seen from the detection building. Slight different are evidenced between the two pattern of emission.

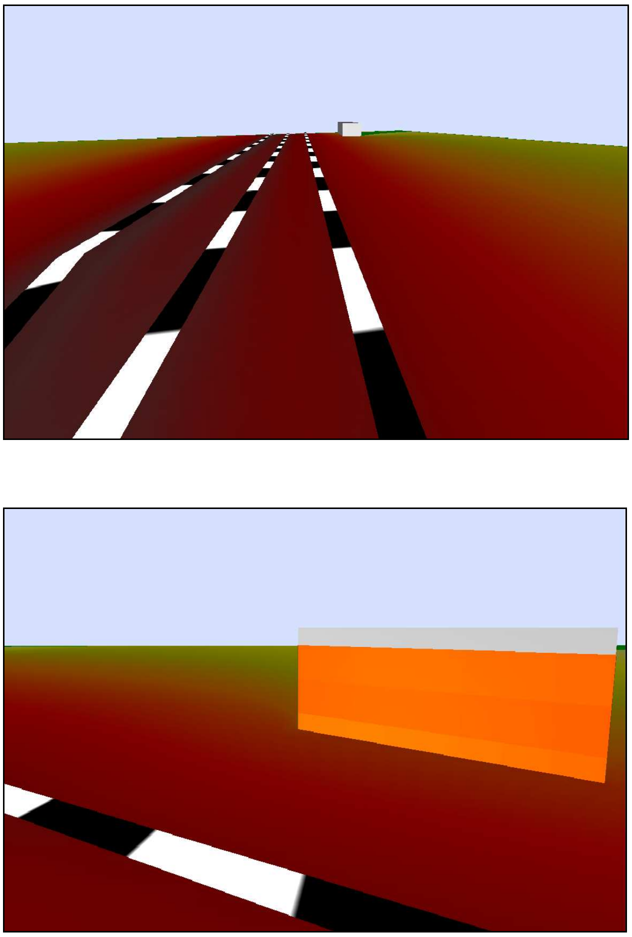


Fig. 6 3D maps of noise emission due to the station environment as generated by our model. The colour gamma is the same of Fig. 5. Top: portrait vision of noise emission along the railway on the right there is the observation building. Building. Down: noise evaluation on the building façace.

Fig. 6 gives different aspects of such analysis. We provide a four panels picture of the spatial evidence related to the averaged signal. The CadnaA function used is "3D special". On the top left we show a landscape vision of the noise emission such as the observer is placed in front of the detection building, looking towards the station. The top right panel gives, on the other side, a direct vision of noise emission on the building façade, while the down left provides the same image but with a lateral perspective. We can observe a clear difference of the L_n signal when considering different angles of the building.

This gives a first interesting result since this kind of predictive approach can suggest what are the areas which need an external intervention in order to make safe the environment.

The down right picture furnishes the same vision of top right but this time we display the numerical value of the L_n at several point of the façade, taking into account that the building is divided into three floors. This result furnishes an analytical prediction of the noise experienced on the building and can be matched with the experimental results discussed in the previous paper [4].

As a matter of fact, exploiting 3D mapping represents a very useful tool in order to establish what zones of the area under investigation require to be more careful analyzed. In fact, this study can suggests, taking into account significant ambits, what are the areas which really need some improvements, allowing to intervene in the most suitable manner to face issues induced by acoustic pollution.

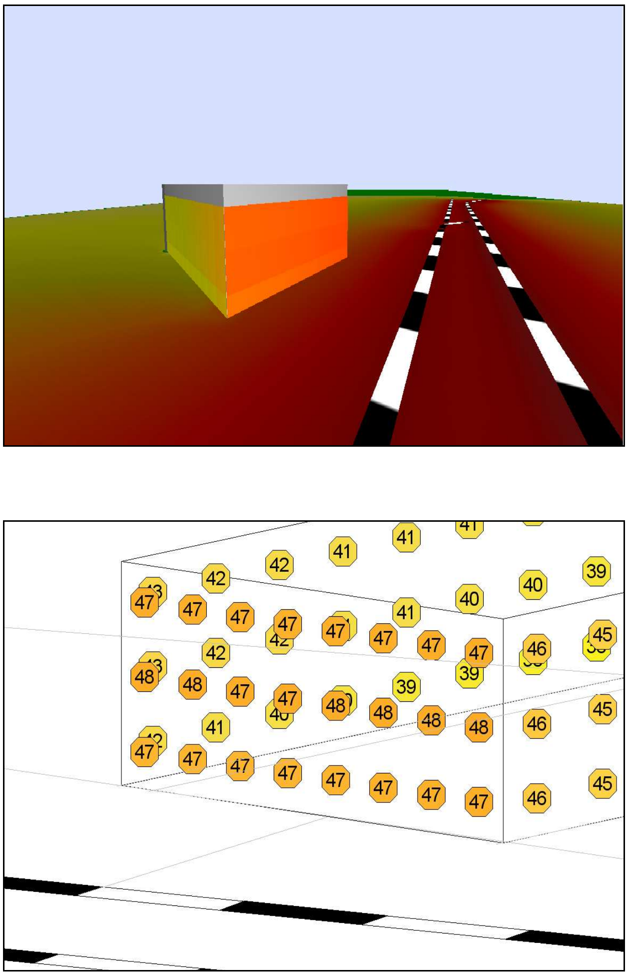


Fig. 7 3D maps of noise emission due to the station environment as generated by our model. Top: lateral vision of noise emission on the building façade. Down: building noise evaluation with numerical predicted values.

The 3D mapping obtained by means of the simulation we have proposed allows to draw some interesting considerations. From the portrait vision of the area under investigation provided in Fig.6 one can obseve that the highest values of emission are produced in the neighbourhood of the railway line and that the signal lowers very quickly according to the emission of a line source. The same consideration can be obtained from the down panel of Fig.6.

As one can observe from Fig. 3, an average of the full time-history detected during the data taking suggests a L_{eq} which is about 50 dBA according to the definition of L_{eq} (1). Such a value is compatible with the simulation we have proposed. In fact, the down panel of Fig. 6 and Fig. 7 indicate that L_n values is attested around 47-48 dBA in relation to the height of the building at which one measures noise emission. Such a result points out that developing a suitable code in order the check noise emission in a well defined urban framework can be physically significant and allowing to approach the issue in a general manner by taking into account environment characteristics.

In order to further confront our simulation with the measured data we have even developed a simulation scheme which considers a train transiting in a certain region as a linear source of definite length and of well defined acoustic power framed in the same area. In order to check the instantaneous emission of the source we have made to run sources along a reference time which is equivalent to the integration time imposed to obtain the equivalent level of emission. As a matter of fact considering the definition of equivalent level (1) we obtain that $L_{eq} = L_p$ and our simulation is roughly coincident with the simulation of the L_I of the given source. As we can se in Fig. 8 and Fig. 9, in relation to the relative position of the train we have different pattern of equivalent level and even of the expected data at the detector, which can be compatible with the experimental results.

It is evident that the simulation by means of linear sources allows to draw some interesting considerations. Actually, Fig. 3 suggests that high velocity trains and intercity trains generate typically 80-85 dBA of emission when measured on the building façade. Other transits generate a signal ranging from 70 to 75 dBA. Now, if we read out the second line of Fig. 8 and Fig. 9, we observe that in the case of sources generating a 120 -125 dBA of emission (i.e. in the case of high velocity trains) and transiting in front of the detection building, the predicted signal can be respectively of 74.8 dBA and 79.8 dBA which represents a quite encouraging prediction if we take into account the simplicity of the adopted model.

The third line of Fig. 8 and Fig. 9 suggests that if we place the source on the intermediate railway the predicted L_i is lowered of about 5 dBA each according with the scaling of a linear acoustic emitter and again matching experimental measures of trains moving on the inner rail tracks.

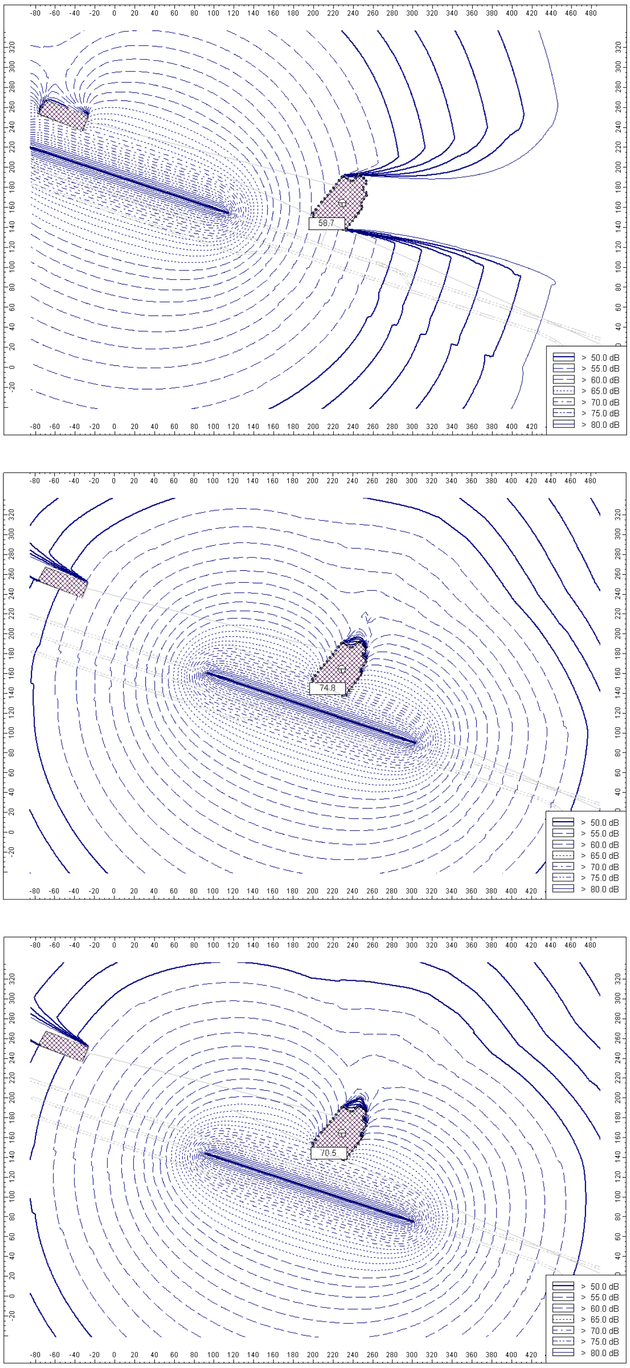


Fig.8 Simulation of train transit by means of a linear source. Left column: (top) a 120 dBA train transiting at the station level, (middle) a train with the same emission power in front of the detection building, (down) the same source placed on the intermediate railway.

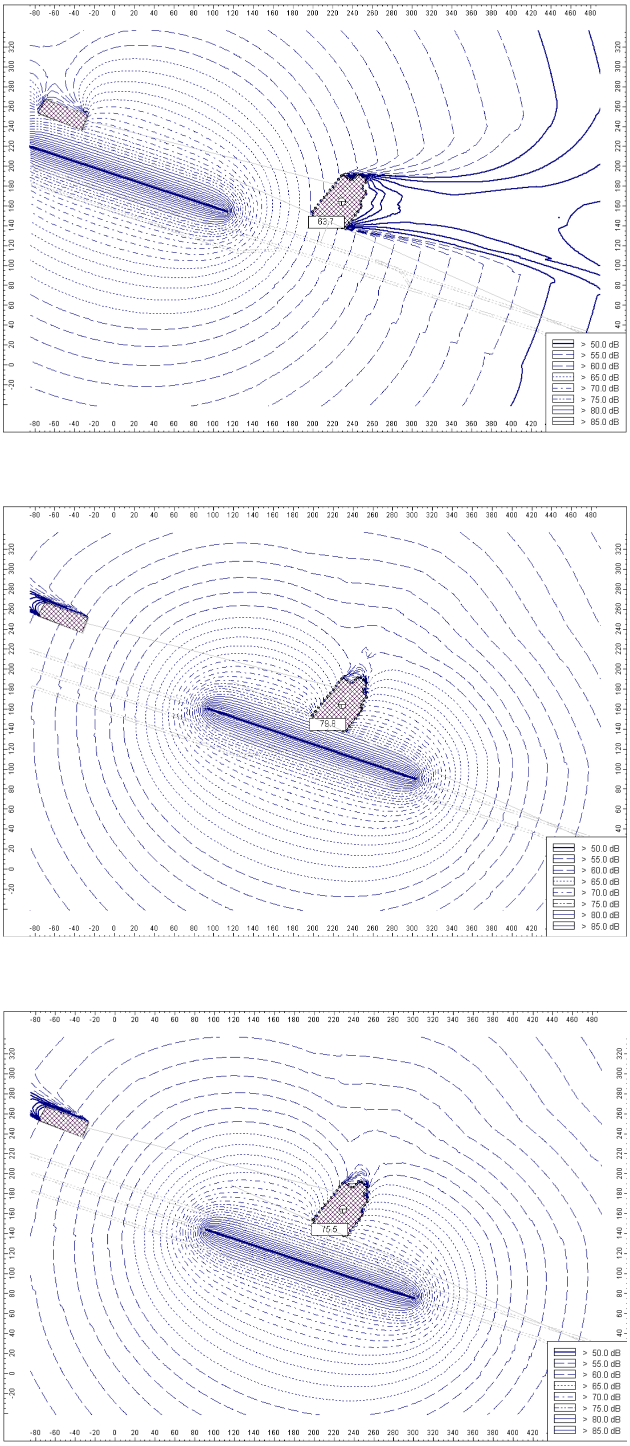


Fig. 9 The same as Fig. 7 but with a linear source endowed with 125 dBA of power level. Numbers on the frame of each picture are distance measures provided in meters.

Upper row of Fig. 8 and Fig. 9 is dedicated to simulations which consider "train" in proximity of the station building. In other words this case coincides with observing a high velocity train moving from the station. In these hypotheses, on the building façade, it is detected a signal of 58.7 dBA (for the 120 dBA source) and 63.7 (125 dBA source).

Let us consider the last case showed in Fig. 10, two "high velocity trains" respectively leaving the station and crossing over the exchange between the external and the inner rail track.

In such a case there is a combination of the two emissions with a prediction of the detected signal which is around 71.0 – 75.1 dBA respectively in the case of a couple of 120 dBA emitters and in the case of a 80 dBA plus a 125 dBA emitter. In the latter case, it is evident from the plot (down side of Fig. 9) that the 80 dBA source is almost negligible with respect to the 125 dBA one.

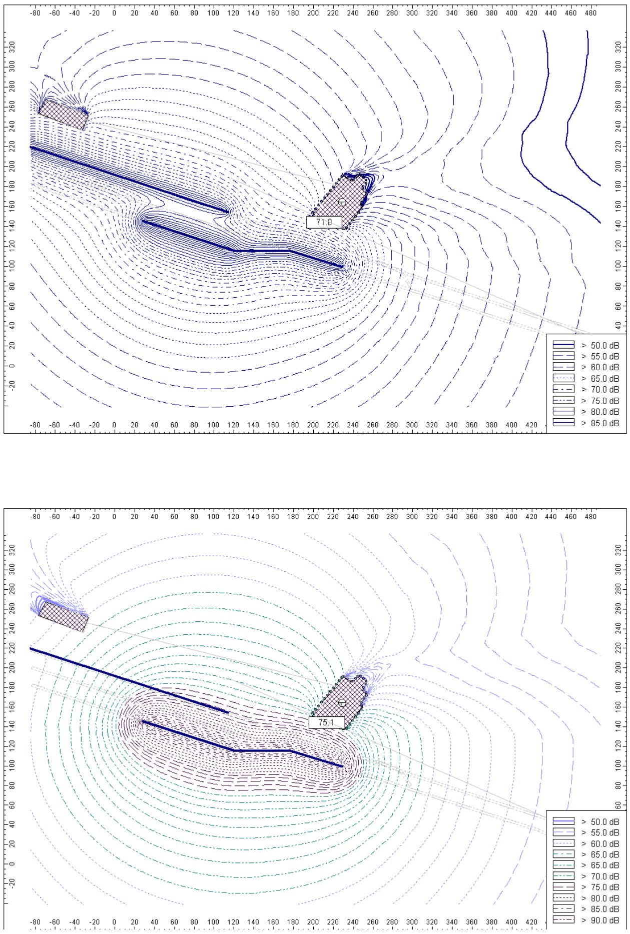


Fig. 10 Two linear sources both framed at the level of the station building and moving across the exchange placed in the neighbour of the building. Left: the two sources endowed with 120 dBA of power level; right: in this case the two sources are equipped with 80 dBA and 125 dBA of L_w respectively. We draw this last picture contour lines with colours in order to make clearer the wider range of values explored.

5 Conclusions

Predictions of an acoustical simulation software developed in the framework of a urban area subject to low speed train transits has been proposed. We modeled the railway setting around the station of a small town in the south of Italy by means of the CadnaA program, exploiting the built in package of this software based on the SRM German model of railway noise. The result of this study demonstrates that the software simulation can be rather satisfactory according to the experimental measurements. In addition the representation facilities of the software allow to develop false color maps and 3D pictures which immediately furnish a view of the acoustical L_{den} pattern experienced on the areas under investigation. Such achievement suggests that a careful employ of a predictive software, without recurring to analytical studies or too long experimental campaign, can, as a matter of fact, easily highlight what are the areas characterized by critical noise conditions. In order to approach the problem from a different point of view, in the second part of our paper we have developed a very simple analogy between railway effects due to train transits in a certain environment with acoustical effects of geometrical sources like segments (endowed with a suitable acoustic power) in the same area. This analysis suggests that under certain conditions and by opportunely tuning the geometry and the acoustic power of the source, train transits can be mimicked by simple geometrical models with a satisfactory approximation degree. Such a result, which could represent a useful scheme in order to study certain emission configurations of railway frameworks, will be argument of further more general investigations in other forthcoming studies.

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