An Acoustical Study of High Speed Train Transits

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Abstract: - In this paper, the comparison between experimental acoustical data and predictive software simulation is performed. The area under investigation contains a high velocity railway and it is very interesting in terms of geometrical features and environmental conditions. In a recent paper, the experimental campaign has been presented and a preliminary model has been tested with that measurements. In this work, we continue this analysis approaching an acoustical predictive software, CadnaA by Datakustik, and checking its response with respect to the experimental data. The need of a precise modelling is underlined, since the results of acoustical simulations are strongly affected by the number of sources included and their sound power level. Particular emphasis is also given to the representation of results, focusing on the production of "easy to read" maps. In the last part of the paper, noise coming from high velocity trains has been modeled as noise coming from simple geometrical elements, such as points and segments. The comparison between these simulated values and the experimental data is performed and appears to be an interesting basis for forthcoming studies.

Key-Words: - High speed train, noise detection, simulation model, predictive software.

1 Introduction

During last years, train industry has undergone a period of improvement and innovation, especially in the high-speed vehicle technology. This is particularly due to the growing necessity of an efficient transport system in order to compete with airplane and automobile vehicles. Such a perspective is even strongly stimulated by the nowadays economical emergency which affects world finance all around the world. This issue, in fact, suggests to develop less expensive infrastructures and to consider means of transportation capable to lower states expenses.

Actually, as it is well known, train transportation can play a very significant role in this sense since it allows to combine practical peculiarities and economical advantages. As a matter of fact, studies about this topic seem to be a very relevant task, especially if the environmental consequences of such a transportation system are considered.

Let us remark that 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). In particular, technological advancements have grown together with engineering problems such as the increment of aerodynamic drag ([1], [2], [3], [4]), and the stability of the vehicle, while, in the meantime, issues related with noise pollution have significantly grown up.

A general approach to railway noise suggests to consider some fundamental parameters: speed of the train, 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). Moreover, noise can be generated in stations because of running engines, whistles and loudspeakers, and in marshalling yards because of shunting operations.

High-speed trains represent a relevant phenomenon when dealing with noise pollution. This kind of infrastructure is in fact responsible of special noise problems with sudden, but not impulsive, rises in the sound level emission. At speeds greater than 250 km/h, the amount 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 (e.g. acoustical barriers, magnetic levitation, etc.) will not be expanded. [5]

The problem of noise pollution in urban environments is a quite relevant framework of modern applied physics and engineering. This issue can be of fundamental importance when a new infrastructure has to be settled down, that's why an exhaustive study of the problem represents a basic moment of whatever preliminary planning program. In this paper we investigate the performance of an acoustic simulation software when a systematic analysis of noise pollution is performed with respect to a definite framework. The specific area under study is the countryside of the small village of Castro dei Volsci in the neighbourhood of Frosinone (Italy), where a high velocity railway is positioned (Fig. 1).

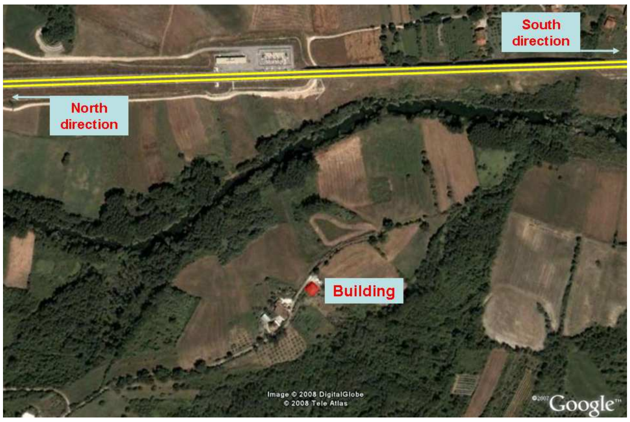

Fig.1: Aerial photogrammetry of area under investigation.

Actually, in a previous works [6], some of the authors investigated this area performing acoustical noise measurements with a detector placed outside a building which was located in front of the high-speed railway (about 300 m far from the rail line), as shown in Fig. 1. It is important to remark that, at that time, the railway was operating in a test drive configuration. The 8 transits, occurred during our measurement time, were the only transits on that dedicated railway and they occurred in quite identical values of speed, load and other running conditions because of their test nature. For this reason our measurements have also a quite relevant historical interest.

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 collected data have been processed with the *dBTrait* software licensed by 01dB. These data, shown in Fig. 2, represent a useful starting point for a predictive simulation. We developed a predictive model by using the algorithm implemented in the software CadnaA by DataKustic, in order to describe the acoustic emission by the different sources present in the area, as we will describe later. The theoretical results have been then checked with the experimental measurements of the previous campaign, comparing false colours maps of the expected sound emission on the area with the evaluation of the equivalent sound level at the detector. As we will see in the next paragraphs, false colours maps represent a very useful tool in order to obtain a by-eye evaluation of the average noise level induced in the urban area during the time of transits. Therefore they can be used in a significant way to highlight critical zones from the acoustical point of view.

A further investigation has been performed developing a simple model of train noise emission on the basis of some elementary geometrical sources. In particular, we mimic a train with a linear emitter or with the combination of a pointlike acoustical source, in charge of simulating the railcar, and a linear one, in charge of simulating the train vehicles.

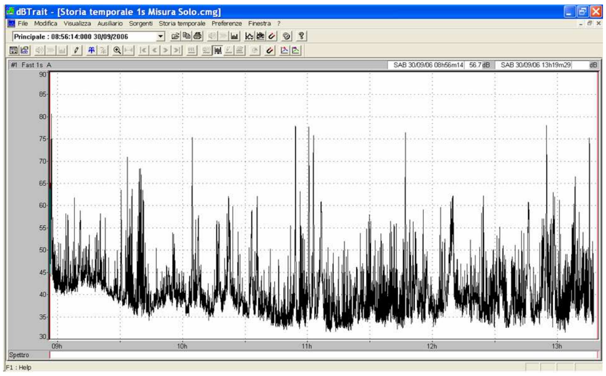

Fig.2: Time history of whole acquisition period in the ***dBTrait*** frame. Noise level [dBA] versus time [s] is plotted.

2 Environment and experimental set up description

As said in the introduction, the high velocity railway under investigation is placed in the countryside of Frosinone province. The detection apparatus has been placed outside and inside a building (for details see [6]) situated at a distance of about 300 m from the railway. Its position is higher with respect to the railway so that the "acoustical visual angle" is very big and consequently the corresponding rail line is around three kilometres long.

In the neighbourhood of the railway there is a building placement related with a small village hamlet. The environment is characterized by some buildings and some roads which are not so far from the railway embankment and have to be taken into account in order to have a satisfactory predictive simulation. From the experimental point of view a set of three microphones was prepared, one outside the reference building, and two inside of it. The microphones belong to the first precision class sound level meters and they are part of a complete acoustical system, in fulfilment with art. 2 of Italian D.L. 16/03/1998.

3 Simulation algorithm

In this section we will discuss the simulation process we have implemented by means of the CadnaA software.

This 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.

In order to model the high velocity railway we have exploited the built-in package of CadnaA related to train acoustic emission. The emission level for railways is in this sense calculated according to chosen guidelines. In particular we developed our simulations according to SRM II (Reken-en Meetvoorschriften Railverkeerslawaai '96) model which takes into account the Netherlands national computation method for railway noise emission published in [7]. This model is recommended by EU commission guidelines as indicated in 2002/49/CE. This approach envisages that one has to input in the calculation code the train typology, the number of transits on the railway in the time-interval submitted to the simulation process and the tracks characteristics. It has to be remarked that the software answer furnishes the consequent L_{den}, i.e. the equivalent sound level obtained integrating the emission during the whole night and day railway functioning. Of course, by opportunely tuning the calculation algorithm, one can obtain L_d or L_n, that are the equivalent sound level evaluated respectively during day time and night time, in relation to the preferred quantity to be calculated. Since in our case we are interested to day transits, we restrict the simulation time to some hours of the day in correspondence to the time interval monitored by detectors in the measurements campaign. In particular, we simulate 4 high velocity train transits, both in the North direction and in the South direction, that are the only transits that occurred during the measurement period, during the interval ranging from 08.00 a.m to 02.00 p.m., according to the results of [6]. The calculation grid has been constructed in such a way to have detectors placed at the middle of a $25 m^2$ square, at the height of 4 meters each. In this simulation we have not considered any meteorological corrections.

In order to have a satisfactory prediction in term of the equivalent level L_{den}, one should take into account even the other noise sources present in the environment under analysis. This issue is very important when the purpose of an acoustical investigation is to have a noise map prediction. In fact only a suitable description of the several sources, which are responsible of noise pollution, can lead to draw interesting information on the environmental effects of infrastructural systems. Actually, in our case, together to the railway emission, we consider the noise coming from the averaged effect of roads which are in the neighbourhood of the train tracks. Moreover we measured the background noise, in order to simulate it with a pointlike source close to the virtual receiver position, emitting with a suitable sound power level. Since the area under investigation belongs to a countryside environment, roads have been modelled as local roads, considering a rate of transit of 100 cars/day, with a speed limit of 60 km/h. Route prediction has been elaborated by means of the simulation algorithm based on the French model NMPB-Routes-96 [8].

The simulation scheme, developed as above, has been then run into the CadnaA software in order to obtain different noise maps or contour curves. Let us remark that we employed the considered software both under the predictive point of view and the representation one. In fact, a clear and easy to read representation of the simulation results can provide a direct feedback of the expected noise in correspondence of the observation point, easily comparable with the experimental detection.

4 Results and discussion

As suggested in the previous section, once the whole set of noise sources has been built-in and characterized, one can easily obtain the acoustic noise emission. In the case under investigation, the interesting conditions of experimental area, in terms of geometry, environmental features, building position, etc., favour the simulation program and the discussion of the results.

As one can see from the aerial photogrammetry (Fig. 1), the building where detectors were allocated is placed in front of the railway line, having on its left the North direction and on its right the South one. The distance building-railway is about 300 m.

In Fig. 2 and Fig. 3 we show respectively the full time history obtained during the measurement period and the L_{fA} which is the Fast sound Level with A-weighting signal, obtained considering four transits in South direction and four towards North. The alignment is obtained by centering the four peaks in 1 minute and 30 seconds plot interval.

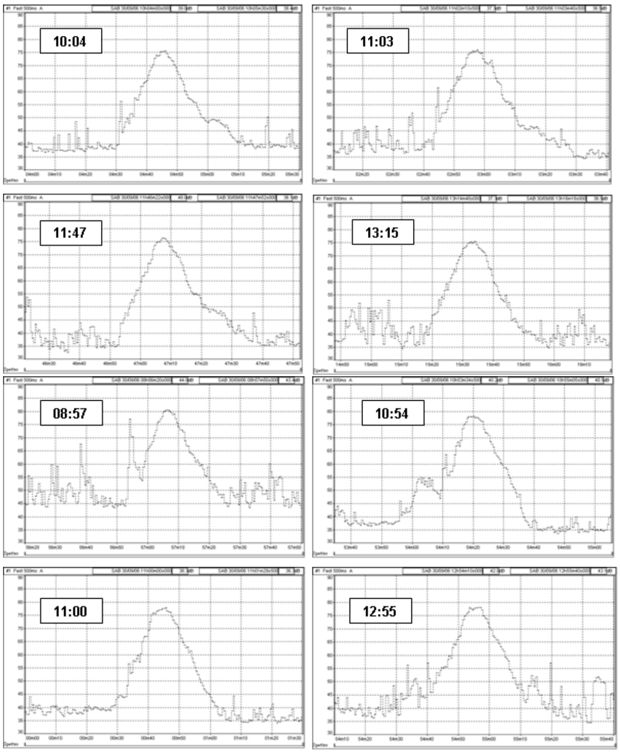

Fig. 3: Signals related to four transits in South direction (up) and to four transits in North direction (down). Noise level [dBA] versus time [s] is plotted. Time of transit is reported in the box.

As first remark, we can observe that from Fig. 2 one can measure a L_d signal which is about 50 dBA. Considering only the railway source, the predictive calculation, given by our simulation, provides a noise map which is showed in Fig. 4 as contour plots superimposed on the aerial photogrammetry of the area. In order to have a more “easy to read” view, we furnish the same noise map overlapped to a vector description of the area in Fig. 5.

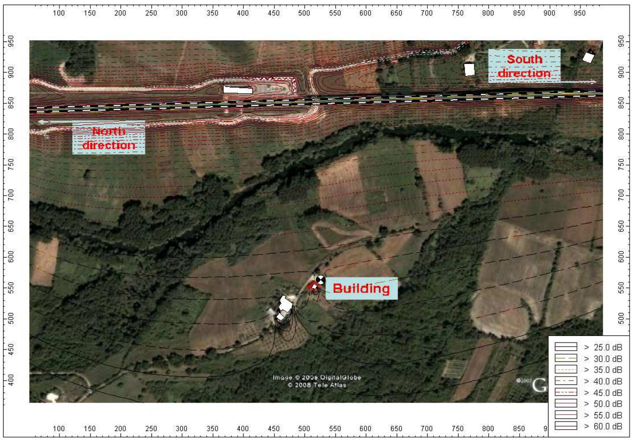

Fig. 4: Acoustic contour plot of the L_d emission overlapped to the aerial photogrammetry of area under investigation. We have evidenced only the railway and the virtual detector. Numbers on the frame of the figure are distance units provided in meters.

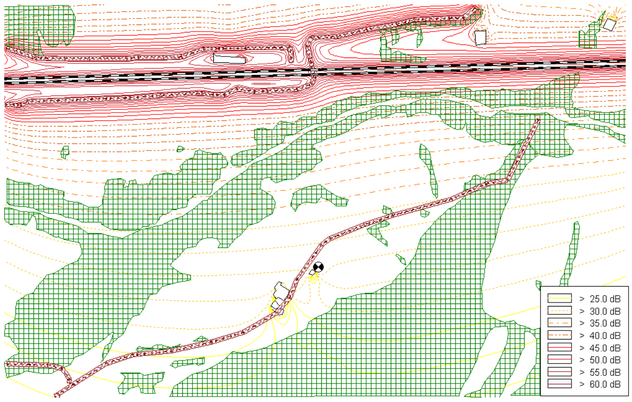

Fig. 5: Acoustic contour plot of the L_d emission overlapped to a vector description of the area under investigation. In this case we have evidenced the railway, the road paths and the detector

From Fig. 5, one can notice that the receiver is placed in a region in which the equivalent level of emission is comprised between 30 dBA and 40 dBA. This result strictly depends on the fact that L_d represents an average of the acoustic emission mediated on the whole time of detection, thus it is not surprising to obtain such a low value of the acoustic level. Actually this represents a first signal of how using a predictive software in order to calculate the acoustic level emitted in a certain environment, represents a very delicate task. In fact, it is quite hard to describe opportunely all the effective noise sources spread all around the area under investigation, and this conundrum turns out to strongly affect the phenomenological prediction one is developing. Despite this important problem, since at this level our description intends only to investigate the phenomenological capability of the software, one can draw, in any case, some significant hints by exploiting the software prediction.

Let us remember that in order to make our description more adherent to the real situation, we have added a pointlike source in the proximity of the receiver. This source is endowed with a suitable sound power level, so that to simulate the background noise of environmental origin during the whole time of detection. This option allows to obtain a different pattern of the contour plot in the neighbourhood of the building as we show in Fig. 6.

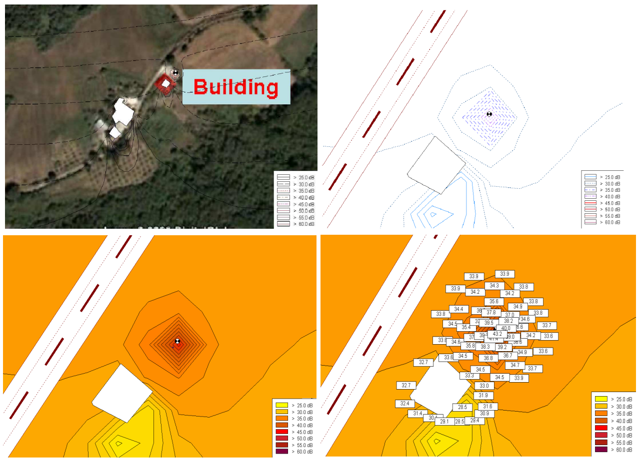

Fig. 6: A collage of different plots obtained by means of the CadnaA simulation regarding the area where the receivers have been placed during the experimental measurements and where the virtual detector has been framed.
a) (Up left) Area we are referring to.
b) (Up right) Same detail characterized by means of contour lines describing the L_d.
c) (Down left) Noise map of the area.
d) (Down right) Noise map of the area with an explicit description of local values of the day level L_d in dBA.

Actually these results suggest a day level of the acoustic emission which is comprised between 40-45 dBA. This achievement is roughly according with the average of the full time measurement provided in Fig.2. As a matter of fact, our simulation suggests that when we want to take into account averaged acoustic indicators, the anthropic noise represents a quite relevant factor. On the other side, since infrastructural noise is very relevant as instantaneous signal, it seems that one has to be very carefully with the editing of noise maps when these are used as indicators of sources potentially annoying human wellness.

Actually the simulation results suggested by CadnaA seem to be comparable with the experimental results in the receiver region. In fact, despite the intrinsic difficulties in characterizing the whole set of acoustic emitters, the addition of a pointlike source mimicking the background noise seems to be a significant improvement in order to have a physically significant result, at least at the detector level. As one can easily see from Fig. 5, the obtained acoustic maps represent a very powerful tool when one is interested to a phenomenological analysis of the noise emission in a well defined region. Therefore, combining the predictive software simulation and experimental results can represent a very important phase in the acoustical analysis of the area. In our simulation we have neglected the terrain orography, which can represent a significant peculiarity of the environment one is considering. In particular orography can strongly influence noise propagation. For example, valley can overdraw the acoustic signal by means of multiple reflections or distortion of wavefronts because of the different level of atmosphere density at different points of the area. Actually, dealing with this kind of problems represents a very complex task in a predictive simulation. However, taking into account experimental measurements can allow to refine the simulation code. In this sense, observing the discrepancies between the predictive map and the experimental data allows to implement suitable corrections to the algorithm in order to render more realistic the simulation. This approach can be particularly significant when one wants to develop a basic algorithm which needs only to be generalized so that to be favourably used even in other contexts.

5 Modelling train transit with simple geometrical sources

Let us put our level of investigation a bit further on. Up to now we tried to exploit the software capability in the predictive framework. A different approach is to attempt a modelling of acoustic sources under investigation by means of very simple emitters featured opportunely in term of geometrical sources.

Since we are dealing with railway acoustic emissions, the simplest approach one can consider is to describe a train as a linear source emitting with a suitable power level which accords with the physical features of the train. Despite the several kind of "ad hoc" model which one can find in literature, we are interested in verifying what are the discrepancies coming from the choice of a very simple description, i.e. the one we are adopting, and the experimental results. A good agreement with data could, in fact, suggest that, in the case of particular environment, dealing with a sophisticate model can be superfluous when the required results wants only to explore phenomenological aspects of the problem, such as the calculation of a predictive noise map.

Fig. 8 collects the transit along the railway under investigation of a linear source of 200 meters length, endowed with a power level of 130 dBA. In order to make significant the simulation, since the software CadnaA is conceived to provide equivalent levels of the acoustical emission, we have integrated such a source during a certain definite time considering its emission constant during this time interval, so that L_d is equivalent to the instantaneous L_p. The obtained result displays that, during a transit of a linear source, there will be a peak in the time history of the L_p. The maximum of emission, which is 78.2 dBA, is reached when the train is in front of the detector, while there is a gap of about 3 dBA when the source is approaching and moving away. Such result is quite similar to what has been obtained in the reality (see Fig. 3). The real curves show, in fact, a L_p behaviour which has a maximum ranging between 80 to 85 dBA, for different transits, with a gap of about 3 -5 dBA during the transit, as obtained in [6] (see Fig. 7). The differences in the emission level can be justified considering that we have not modelled the natural features of the environment. In fact, as already discussed before, one should take into account that the presence of depressions could magnify the signal by means of multiple reflections so that one can observe at the detector an higher value of the power emission with respect to the intrinsic signal which one should measure at that distance.

It is important to stress that a linear source, such as the one we have considered, implies a symmetric response with respect to the peak of the signal at the receiver. This seems to be in disagreement with the profile of the experimental measurements of Fig. 3, where there is a constant delay in the decay or in the growth of the emission level in the South direction. In fact we observe a signal slope which is, in the South direction, very steep when the train is approaching and very shallow when it is leaving, and vice versa in the opposite direction. Such peculiar behaviour needs a further investigation. Thus, in order to explore a different approach, we developed a different scheme to describe train emission. In such a case we considered the sum of a pointlike source (130 dBA of sound power) describing the railcar and a linear one (110 dBA of sound power) describing the vehicles. At this level it is important to remind that high velocity trains can have the railcar either at the beginning or at the end of the train. In our case, the railcar was placed on the right side of the segment, as simulated in our model. As in the previous case, we have run the code for an integration period which is equivalent to the emission time, so that to have L_d = L_p. The obtained results are displayed in Fig. 9. It is easy to see that in such a case we observe a different behaviour. In particular, in the North zone and in front of the detector, the measured L_p ranges between 75 and 80 dBA, while, when the toy-model source is in the South area, we obtain an emission which at the detector is comprised between 70-75 dBA. In other words, when our "toy train" is moving towards the South direction there is a steeper grow of the L_p when the train is approaching and a slower decay when it leaves. Confronting this behaviour with the experimental results, we are not able to simulate train transit in a satisfactory manner. At this level, in fact, the simple model we have described is not able to perfectly explain this issue, nevertheless we are confident to improve our analysis in a forthcoming investigation by developing more complex models in term of geometrical sources aimed at better describe train transits.

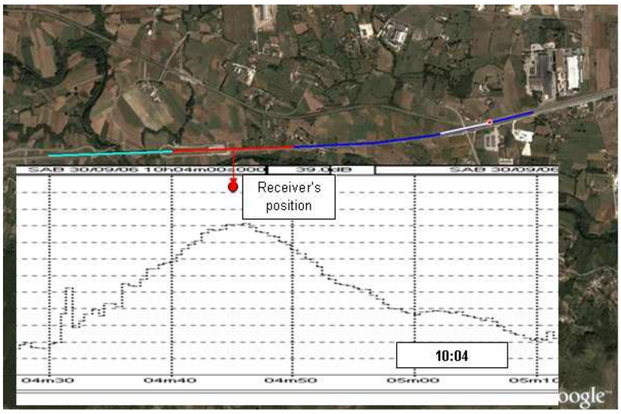

Fig. 7: Superimposition of train transit signal (top left signal in Fig. 3) and rail line. On the y axis we have the fast sound level in [dBA], while on the x axis we have time in [s].

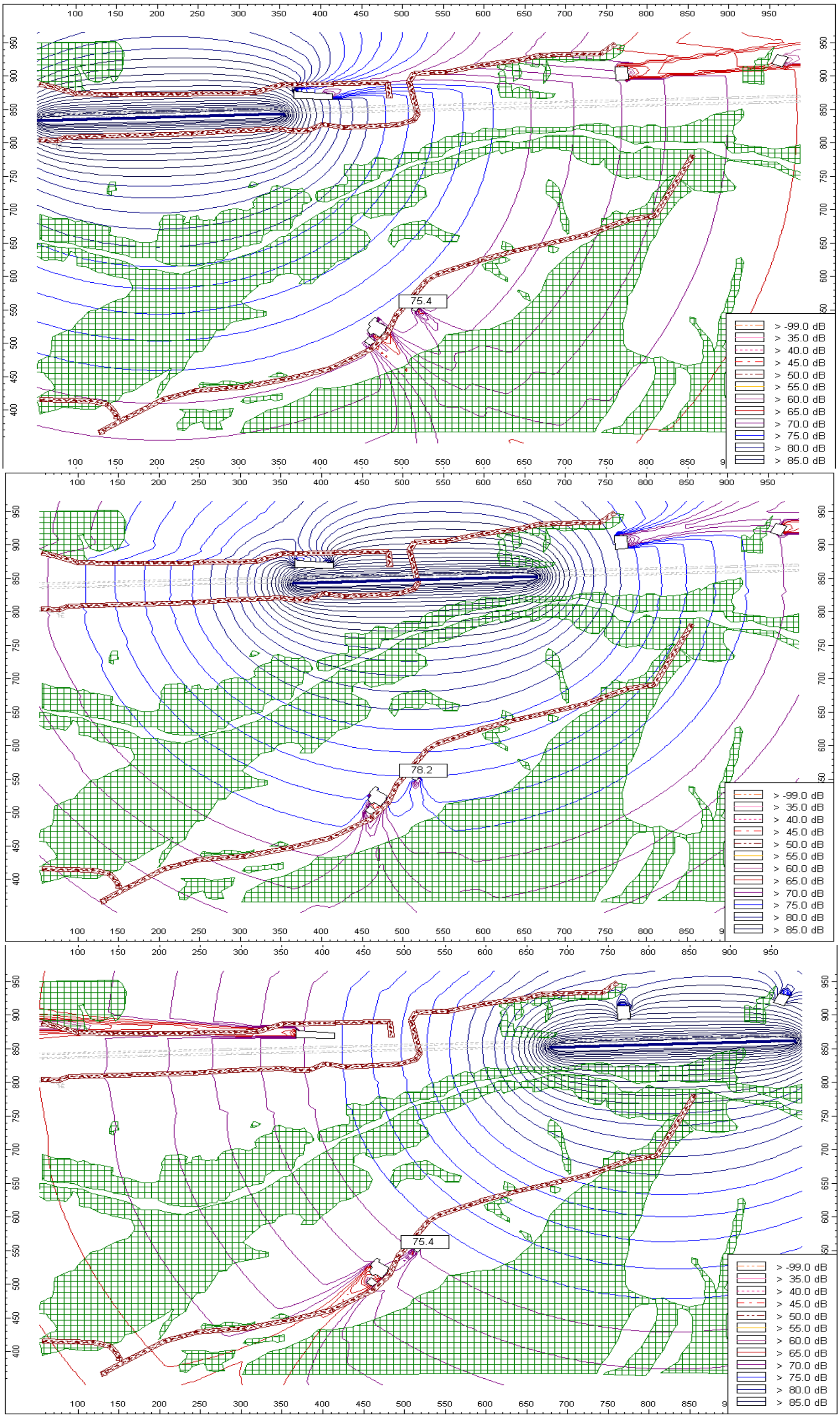

Fig. 8: In this figure we show the L_d contour level when the train transit is simulated by means of a linear source of 200 m. The virtual detector value is displayed at each transit.

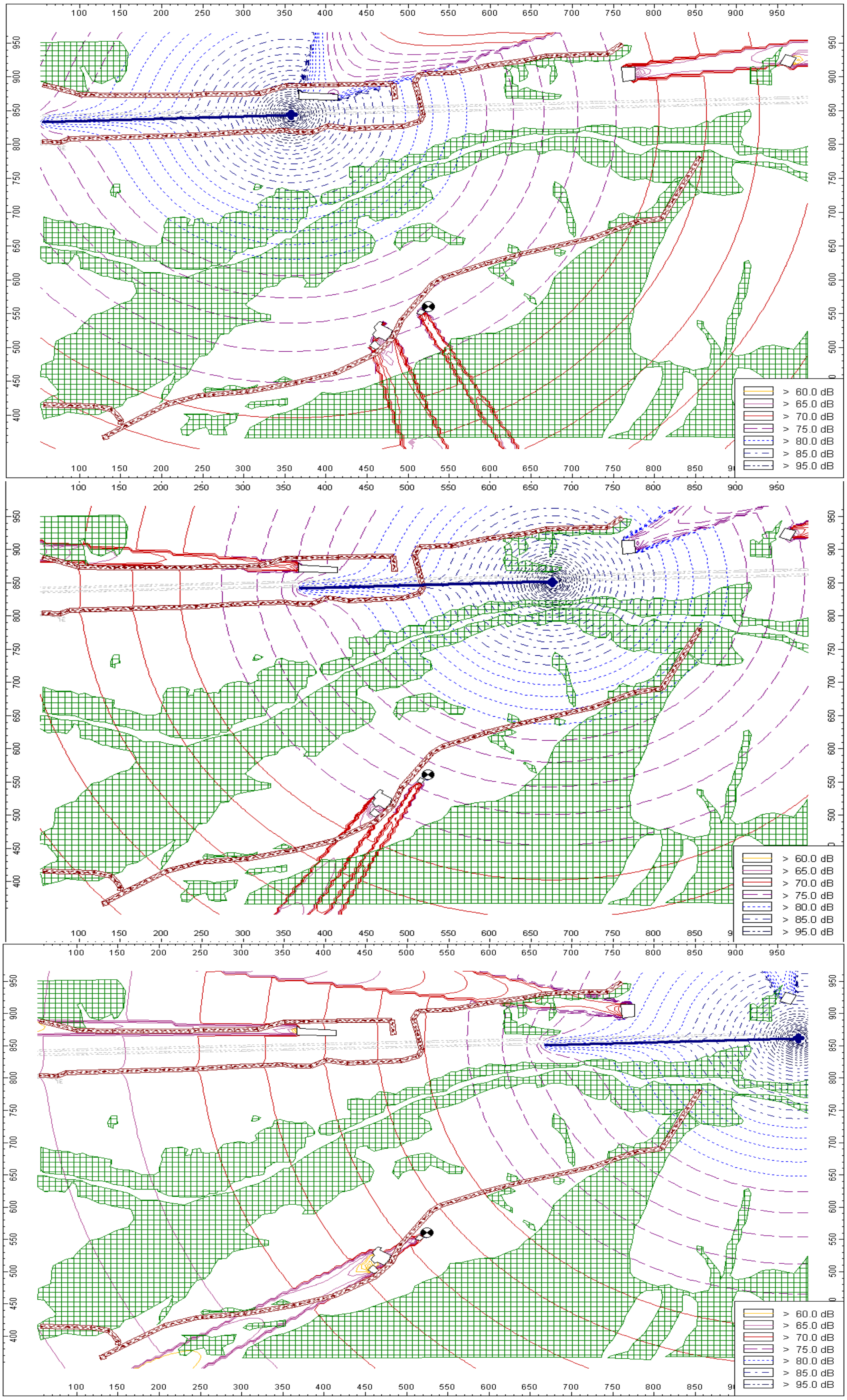

Fig. 9: The L_d contour level when the train transit is simulated by means of a linear source of 200 m and a pointlike source.

6 Conclusions

In this paper we showed an almost complete acoustical analysis of noise coming from high velocity trains, in a countryside area affected by different noise sources. The experimental side of the analysis, detailed in [6], has been recalled in order to perform comparison with the simulation model provided by the predictive software CadnaA. Let us recall that the experimental measurements have been performed in an unique circumstance in which the transits had very similar running conditions because they were test runs. Combining railway, roads and pointlike sources, the latter in charge of simulating the background noise, the simulation results are quite adherent to reality. Moreover, experimental data have been used to tune the model in terms of sound power of the sources and time integration period.

In the end, by using simple geometrical sources, such as points and segments, a kind of "instantaneous picture" of the sound level map has been taken, so that to allow a comparison with the experimental time history of the signal related to a single train transit.

Finally we can conclude that a predictive analysis of acoustical noise in specific areas is a powerful tool to be developed, even if it needs a very detailed description of the environment. In fact, a good agreement between simulation and reality can be reached only if a big effort in this sense is performed.

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