Analysis of Methods to Evaluate the Noise Reduction due to Acoustic Barriers Installation

Claudio Guarnaccia, Joseph Quartieri, Nikos E. Mastorakis

***Abstract*—** Transportation infrastructures represent a relevant noise source in residential areas and have to be carefully taken into account in urban planning. Road traffic is commonly assumed to be the most relevant transportation mean in developed countries. For this reason, road traffic noise can be considered as the most important source of annoyance. The extremely random nature of road traffic makes very difficult to model the phenomenon and give reliable predictions. In the infrastructure design phase, a proper acoustic modelling can be helpful to minimize the noise impact. If the road is already present in the area, it is important to design effective mitigation actions. In this paper, the installation of noise barriers is simulated in a case study. This location, in south Italy, is characterized by several buildings placed in proximity of a motorway. In particular, a new building set has been built just in front of the motorway, without providing any noise mitigation action. In this paper, once the noise map of the area is obtained with a predictive software, the effects of the barriers, measured in terms of noise level reduction, are evaluated by means of literature, regulation and software approaches. The comparison between these approaches will be discussed and will show that, in order to obtain a reliable estimation of the noise reduction, diffraction, reflection and other relevant parameters cannot be neglected.

***Keywords*—** Acoustics, Noise Control, Barrier, Calculation Methods.

I. Introduction

PHYSICAL polluting agents, such as air pollution, acoustic noise, electromagnetic field, are a relevant problem for human activities and their assessment is largely studied in literature (see for instance [1], in which the authors proposed a complex index to include several pollutants). Among them, acoustical noise is largely recognized as one of the most important environmental problem in urban areas and has to be carefully assessed, monitored and, when possible, mitigated. The main noise sources that have to be considered in residential areas are related to transportation infrastructures, since it is reasonable to affirm that industrial areas are distant from buildings agglomeration. The same can be assumed for airport and high speed railways, that usually are settled in peripheral zones and that are modelled by means of advanced tecniques (see for instance [2-7]). These considerations, together with the fact that car is one of the most used transportation mean all around the world, lead to affirm that road traffic noise is one of the most frequent noise problem for residential areas. Several models have been developed to assess the road traffic noise (see for instance [8] and [9]) and several approaches, both statistical and dynamical, have been largely discussed by the authors in [10-16].

The effects of a regular exposure to noise, in general, and to road traffic noise in particular, are deeply studied in literature. In [17], for instance, both the auditory and non auditory effects of noise are described, motivating the need for mitigation actions in particular exposition cases.

In case of road traffic noise, one of the possible intervention is the installation of acoustical barriers along the roads, in order to reduce the sound levels at the receivers, typically residential buildings, hospitals, schools, etc.. The evaluation of the efficacy of a barrier may be calculated in terms of difference between noise levels in absence of the barriers and noise levels after their installation.

In this paper, a case study in south Italy is considered. In of a buildings set beside a motorway is reported, in terms of geometrical and acoustical description. In particular, The hypothesis of barriers installation is evaluated, in particular calculating the noise reduction of different possible solutions, in terms of different height of the barriers and different distances from the centre of the roadway. The calculation methods compared are taken from research literature (Maekawa’s formula [18]), from international regulation (ISO9613 [19]) and from a commercial software framework. The noise reduction is evaluated per each of the three floors of the buildings, in order to highlight eventual differences of barrier performance.

II. Methods

The three methods proposed to evaluate the noise barrier reduction are:

- Maekawa formula
- ISO9613 calculation
- CadnaA software simulation

The attenuation, in general, is given by the difference between the acoustic level in absence (L_{dir}) and in presence of the barrier (L_{screen}):

$$\Delta L = L_{dir} - L_{screen} \quad (1)$$

C Guarnaccia, J. Quartieri, are with the Department of Industrial Engineering, University of Salerno, Via Giovanni Paolo II, I-84084 Fisciano (SA) – ITALY (corresponding: cguarnaccia@unisa.it , quartieri@unisa.it).

N. E. Mastorakis is with Technical University of Sofia, English Language Faculty of Engineering, Industrial Engineering, Sofia 1000, Sofia – BULGARIA (mastor@tu-sofia.bg)

A. *Maekawa's formula*

Maekawa's formula is based on the principle of the difference of path covered by the sound wave. In this scheme, the wave is approximated to a ray and the sound path (shown in Fig. 1) is the connection between source and receiver, in presence and in absence of the barrier.

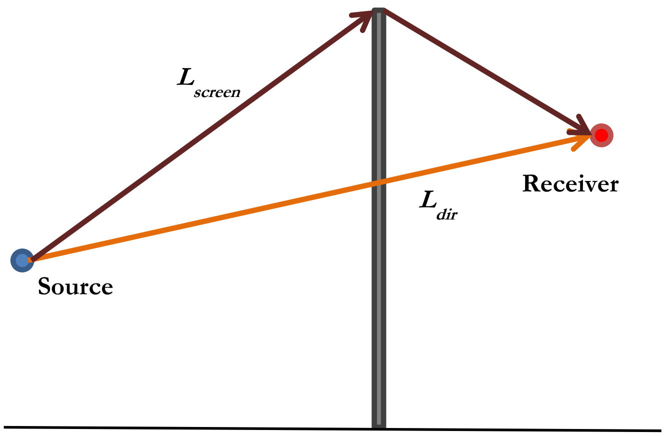

Fig. 1: Sound wave path, in presence and in absence of the barrier.

The attenuation is obtained by the following formulas:

$$\Delta L = 10\,\mathrm{Log}(3 + 20N) \quad (2)$$
$$\Delta L = 10\,\mathrm{Log}(2 + 5.5N) \quad (3)$$

where N is the number of Fresnel. This parameter is defined as follows:

$$N = \frac{2\delta}{\lambda} = \frac{2\delta f}{c} \quad (4)$$

where δ indicates the path difference, i.e. the difference between the path of sound wave in presence and in absence of the barrier, λ is the wave length, f is the frequency and c is the wave speed.

Let us underline that formula (2) is valid in case of pointlike sources, while formula (3) is valid for linear sources. In this study, since road traffic noise, in regular condition of vehicles flow, can be considered a linear source, the authors adopted formula (3).

B. *ISO9613 formula*

The international regulation ISO9613 [19] defines a formula for the propagation of equivalent sound level, in case of down wind conditions:

$$L_{DownWind} = L_W + D_C - A \quad (5)$$

where L_W is the source power, D_C is the coefficient of directivity and A is the attenuation coefficient. The latter term is the most important for our purpose. The regulation defines the attenuation as a sum of several components, related to geometrical divergence, atmospheric effects, ground absorption, presence of obstacles and other various effects. In this paper, the attention is focused on the attenuation due to the presence of obstacles (barriers), that in [19] is defined as:

$$A_{bar} = D_z - A_{gr} \quad (6)$$

Where A_{gr} is the ground absorption. D_z is defined as follows:

$$D_z = 10Log[3 + (c_2/\lambda)c_3\, z\, K_{met}] \quad (7)$$

with:

- c_2 is a constant that considers the terrain effects;
- λ is again the wave length of the octave under study;
- c_3 is equal to 1 in case of simple diffraction, i.e. in our case. This means that the width of the barrier is negligible;
- z is the difference between the sound ray direct path and the diffracted path, and is calculated according to [19]:

$$z = [(d_{ss} + d_{rr})^2 + a^2]^{0.5} - d \quad (8)$$

where:

  - d_{ss} is the distance between the source and the first edge of diffraction;
  - d_{rr} is the distance between the second edge of diffraction and the receiver;
  - a is the distance component parallel to the edge of the barrier, between source and receiver.

- K_{met} is the meteorological correction, that is equal to 1 if $z \leq 0$, otherwise is given by:

$$K_{met} = exp\left[-(1/2000)\sqrt{d_{ss} d_{rr} d/(2z)}\,\right] \quad (9)$$

C. *CadnaA calculation*

CadnaA (Computer Aided Noise Abatement) is an environmental noise predictive software. It can be used for calculation, presentation, assessment and prediction of noise in any area designed in its framework. The general approach is the inverse ray tracing technique. This means that the area under study can be divided in horizontal and/or vertical grids (or grids enveloping all facades of buildings), crossing and merging the contributes of each source operating in the environment. The calculation for some special sources, such as roads, railways and airports, is done considering the technical parameter values, according to the international standards related to each typology of source.

The geometry of all objects present in the area, such as roads and buildings, is taken into account, together with the orography of the terrain.

Further applications of the software, in various conditions and for different sources, may be found in [20-26], in which CadnaA has been adopted both for developing advanced models and for testing real case studies.

III. Case study

The case study in which the methods described in section 2 have been applied is represented by a set of buildings built beside a motor way in South Italy and it is shown in Fig. 2. The motorway is composed of 4 lanes, two in Avellino direction and two in Salerno direction. Other secondary roads are present, even if, for screening purposes, only the motorway will be considered.

The buildings have approximately the same height and the same number of floors. The distance from the road is different according to which building is considered. The position of the agglomeration suggests a strong impact of the motor way on the acoustic point of view. Let us underline that the aim of this paper is not to assess the noise impact on the buildings, but to compare the noise reduction that can be obtained installing acoustical barriers, with different calculation methods.

IV. Software simulation

In any case, it is interesting to simulate the noise map of the area, using the CadnaA approach, in order to understand the possible acoustic scenario of the area under study.

The design of the area has been imported from a DXF file, defining the relevant layers (such as contour lines, roads, etc.). The green areas have been defined and the resulting design is shown in Fig. 3.

The project can be superposed on the bitmap of the area taken from Google maps ©, in order to roughly check the accuracy of the design. (Fig. 4) and to make the simulation the more realistic as possible.

Once the roads and the buildings have been characterized in terms of geometrical parameters, the hourly traffic volumes of the roads, in each direction, have been set up, considering average values taken from field measurements. In addition, the speed limit, the percentage of heavy vehicles and the road gradient have been included in the model. The result of the simulation is reported in Fig. 5, while in Fig. 6 a 3D noise map is plotted, with and without the bitmap of the area.

Of course, the motorway represents the highest source of noise and its impact on the environment must be carefully assessed. The installation of a sound barrier in proximity of the source seems to be the best intervention to mitigate the noise at the receivers. Thus, the effectiveness of the barrier installation can be evaluated in various models, as reported in the previous section.

For the sake of completeness, a simulation of the noise map with the introduction of a standard barrier is performed and reported in Fig. 7. It is evident that the barrier, installed on the left (west) side of the motorway, modifies the noise map at the buildings' façade and in their proximity, reducing the levels and moderating the noise impact. In Fig.8, the 3D visual of the noise levels at the buildings set is reported, in presence of the barrier.

Fig. 2: Case study area, taken from Google Maps ©. The buildings under study are numbered from 1 to 6. The motorway is on the left, highlighted in red.

Fig. 3: Design of the area under study in CadnaA framework.

Fig. 4: Superposition of CadnaA project and bitmap of the area (taken from Google Maps ©).

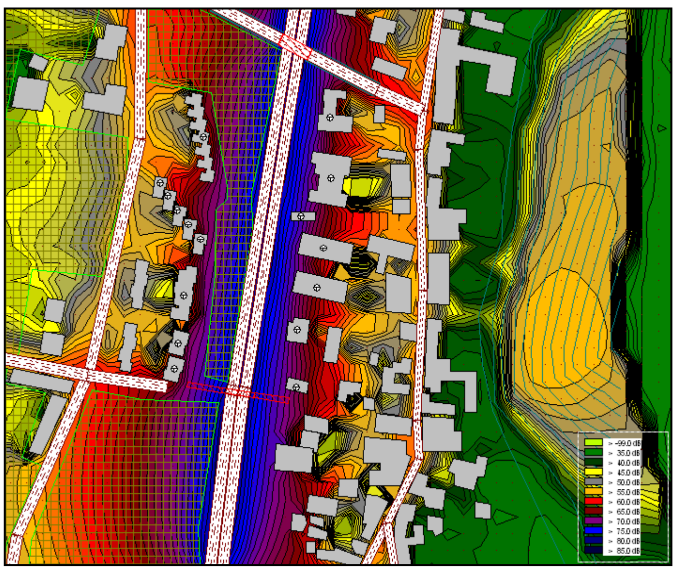

Fig. 5: Noise map of the area under study, simulated in CadnaA software.

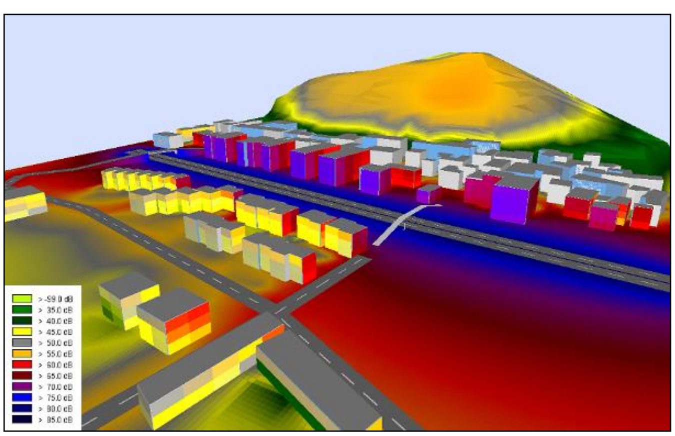

Fig. 6: 3D noise map of the area under study, simulated in CadnaA software, from different visual angle, without (top) and with (bottom) the bitmap of the area (taken from Google Maps ©).

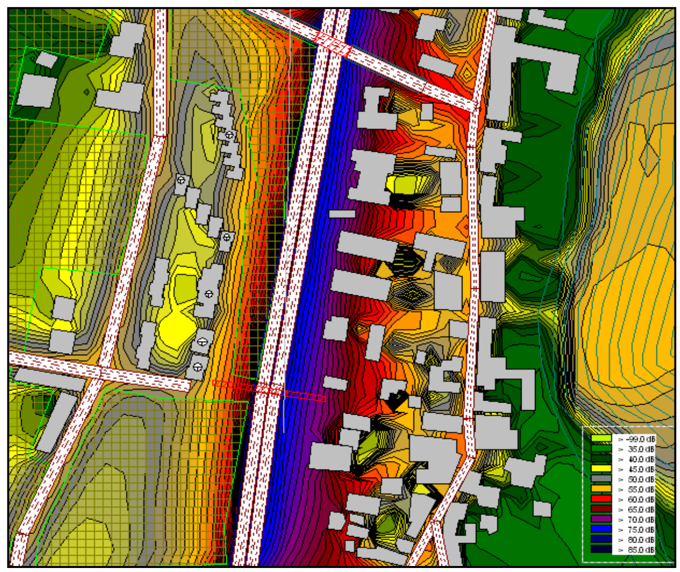

Fig. 7: Noise map of the area under study, simulated in CadnaA software, with a noise barrier on the left side (west) of the motorway.

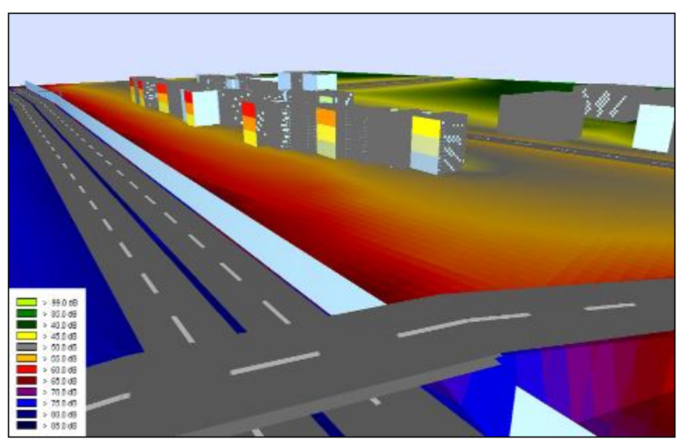

Fig. 8: 3D noise map of the buildings set under study, simulated in CadnaA software, with a noise barrier (light blue), from north visual angle (the barrier is on the west side of the motorway).

V. Analysis and Results

The analysis reported in this section is based on the comparison between noise reduction from barrier insertion, calculated with the three methods presented above (see section II), in different conditions of barrier position (d_s, measured with respect to the centre of the roadway) and height (h_b). Results are reported per each floor of the building (z, height of the receiver, 3, 6 or 9 m)

In tables 1, 2 and 3, the different calculations of the attenuation that can be achieved with an hypothetic barrier placed at d_s = 4.75 m from the centre of the roadway and with different height (respectively h_b = 4, 5 or 6 m), are reported, for all the buildings of the cluster, for each floor (height of the receiver, z = 3, 6 and 9 m).

It is easy to notice that Maekawa's formula furnishes always the highest results, probably because it does not include ground, air and other absorption effects.

In addition, as expected, the growth of barrier height leads to an increase of barrier attenuation. It is interesting to present the maximum and minimum values of this increase, for each calculation method, when raising the height of the barrier from 4 to 5 m (Table 4) and from 5 to 6 m (Table 5). It can be affirmed that increasing the height of the barrier from 4 to 5 m, leads to a minimum increase of the attenuation of about 1-2 dBA (confirmed by all the methods). The same when raising the barrier from 5 to 6 m, obtaining a minimum attenuation of about 1-1.5 dBA.

Tab. 1: Comparison of barrier noise reductions with height h_b=4m and distance from the source d_s=4,75m.

h_b = 4m	d_s = 4,75 m	Noise reduction values [dBA]		
	Height [m]	CadnaA	ISO9613	Maekawa
Building 1	z=3	14,6	15,9	18,3
	z=6	13,1	14,6	16,7
	z=9	10,2	12,9	14,9
Building 2	z=3	14,6	16,0	18,3
	z=6	13	14,5	16,7
	z=9	10	12,8	14,8
Building 3	z=3	14,5	16,0	18,3
	z=6	12,7	14,5	16,6
	z=9	9,8	12,7	14,5
Building 4	z=3	13,1	15,3	18,4
	z=6	13	14,5	17,5
	z=9	11,6	13,6	16,5
Building 5	z=3	14,6	15,7	18,3
	z=6	14	14,6	17,1
	z=9	10,8	13,3	15,6
Building 6	z=3	15,3	15,5	18,4
	z=6	15	14,6	17,3
	z=9	11,9	13,5	16,1

Tab. 2: Comparison of barrier noise reductions with height h_b=5m and distance from the source d_s=4,75m.

h_b = 5m	d_s = 4,75 m	Noise reduction values [dBA]		
	Height [m]	CadnaA	ISO9613	Maekawa
Building 1	z=3	16,7	18,0	20,4
	z=6	15,9	16,8	19,1
	z=9	13,7	15,5	17,7
Building 2	z=3	16,7	18,0	20,4
	z=6	15,8	16,8	19,1
	z=9	13,5	15,4	17,6
Building 3	z=3	16,5	18,1	20,4
	z=6	15,5	16,8	19,0
	z=9	13,1	15,3	17,4
Building 4	z=3	14,2	17,2	20,4
	z=6	14,4	16,6	19,7
	z=9	13,8	15,8	18,9
Building 5	z=3	16,0	17,7	20,4
	z=6	15,7	16,8	19,4
	z=9	13,3	15,7	18,2
Building 6	z=3	16,8	17,5	20,4
	z=6	16,9	16,7	19,5
	z=9	14,6	15,8	18,6

Tab. 3: Comparison of barrier noise reductions with height h_b=6m and distance from the source d_s=4,75m.

h_b = 6m	d_s = 4,75 m	Noise reduction values [dBA]		
	Height [m]	CadnaA	ISO9613	Maekawa
Building 1	z=3	18,2	19,5	22,0
	z=6	17,8	18,6	21,0
	z=9	16,3	17,5	19,8
Building 2	z=3	18,2	19,6	22,0
	z=6	17,7	18,6	20,9
	z=9	16,2	17,4	19,7
Building 3	z=3	18,5	19,7	22,1
	z=6	18,1	18,6	20,9
	z=9	16,7	17,4	19,6
Building 4	z=3	15,4	18,7	22,0
	z=6	15,3	18,2	21,3
	z=9	15,3	17,6	20,7
Building 5	z=3	17,1	19,3	22,0
	z=6	16,9	18,5	21,1
	z=9	15,1	17,6	20,2
Building 6	z=3	18,1	19,0	22,0
	z=6	18,3	18,4	21,3
	z=9	16,8	17,6	20,4

Tab. 4: Maximum and minimum barrier noise reduction variations when increasing barrier height h_b from 4m to 5m.

From h_b = 4m to 5m	Noise reduction values [dBA]		
	CadnaA	ISO9613	Maekawa
MAX	3.5	3.0	3.0
MIN	1.1	2.0	2.1

Tab. 5: Maximum and minimum barrier noise reduction values when increasing barrier height h_b from 5m to 6m.

From h_b = 4m to 5m	Noise reduction values [dBA]		
	CadnaA	ISO9613	Maekawa
MAX	3.6	2.0	2.1
MIN	0.9	1.6	1.6

Tables 6 and 7 report the calculations of the attenuation that can be achieved with an hypothetic barrier of fixed height (h = 4 m) and different distance from the centre of the roadway (respectively d = 5.75 and 6.75 m) for all the buildings of the cluster, for each floor (3, 6 and 9 m). These two tables have to be compared with Table 1, in which a barrier with h = 4 m and d = 4.75 m is considered.

The comparison has been performed plotting values of noise reductions versus height of a barrier placed at 4.75 m, for the first three buildings, per each calculation methods. Results are shown in Fig. 9. Let us underline that the lines are not a fit of the data, but just a guide to the eye. Again it is evident that Maekawa's formula furnishes the highest results. In addition, comparing results at the same floor (solid, dashed or dotted lines), they have a very similar slope, while it is exploited that higher floors have a lower reduction, because of lower difference between direct and diffracted sound rays.

Fig. 9 shows that buildings 1, 2 and 3, that are approximately at the same distance from the motorway (see Fig. 2), have a practically equal behaviour of the noise reduction, when varying the height of the barrier and when considering different floors. In addition, Maekawa and ISO9613 calculations are always overestimating the noise reduction, while CadnaA, that considers much more parameters, seems to furnish a more realistic prediction.

Fig. 10 reports the noise reductions calculated by means of CadnaA method, for all the buildings, as a function of the height of the barrier placed at 4.75 m, at the different floor. Buildings 4, 5 and 6 show a different behaviour, probably because of their special position in the buildings lot (see Fig. 2). In particular, building 4 has a lower attenuation, due to the fact that it is covered by other buildings, thus, also in absence of barrier, the level is lower than the other buildings, reducing the barrier effectiveness. This effect is mitigated at the highest floor (z=9m, bottom plot), where the reduction due to the covering of other buildings is lower.

In Fig. 11, the noise reduction for a barrier of 4 m height, as a function of the distance from the centre of the carriage is plotted for the three floors of building 2. All models seem to confirm the hypothesis that the closest the barrier is to the source, the greater is the reduction. Only CadnaA deviates from this behaviour for the upper floors. This is probably related to effects, for instance reflections from other buildings, not considered in the ISO9613 and Maekawa models.

Tab. 6: Comparison of barrier noise reductions with height h_b*=4m* and distance from the source d_s*=5,75m*.

h_b = 4m	*d_s = 5,75 m*	Noise reduction values [dBA]		
	Height [m]	CadnaA	ISO9613	Maekawa
Building 1	z=3	12,1	15,4	17,7
	z=6	12,2	13,8	15,9
	z=9	11,6	11,8	13,7
Building 2	z=3	13,8	15,4	17,7
	z=6	13,5	13,8	15,8
	z=9	12,6	11,7	13,6
Building 3	z=3	17,1	15,5	17,7
	z=6	16,3	13,7	15,7
	z=9	14,4	11,5	13,3
Building 4	z=3	14,7	14,7	17,9
	z=6	15,0	13,9	16,8
	z=9	14,8	12,8	15,7
Building 5	z=3	17,7	15,2	17,8
	z=6	17,9	13,9	16,3
	z=9	15,5	12,3	14,6
Building 6	z=3	17,6	15,0	17,8
	z=6	17,7	13,9	16,6
	z=9	15,6	12,7	15,2

Tab. 7: Comparison of barrier noise reductions with height h_b*=4m* and distance from the source d_s*=6,75m*.

h_b = 4m	*d_s = 6,75 m*	Noise reduction values [dBA]		
	Height [m]	CadnaA	ISO9613	Maekawa
Building 1	z=3	12	14,9	17,2
	z=6	12,1	13,0	15,1
	z=9	11,3	10,8	12,6
Building 2	z=3	13,9	14,9	17,2
	z=6	13,4	13,0	15,1
	z=9	12,2	10,7	12,5
Building 3	z=3	17	15,0	17,2
	z=6	16,1	12,9	14,9
	z=9	13,8	10,4	12,1
Building 4	z=3	14,6	14,2	17,4
	z=6	14,8	13,3	16,2
	z=9	14,4	12,1	14,9
Building 5	z=3	18,7	14,7	17,3
	z=6	17,7	13,2	15,6
	z=9	16,6	11,4	13,7
Building 6	z=3	16,2	14,5	17,3
	z=6	15,9	13,3	16,0
	z=9	13,5	11,8	14,4

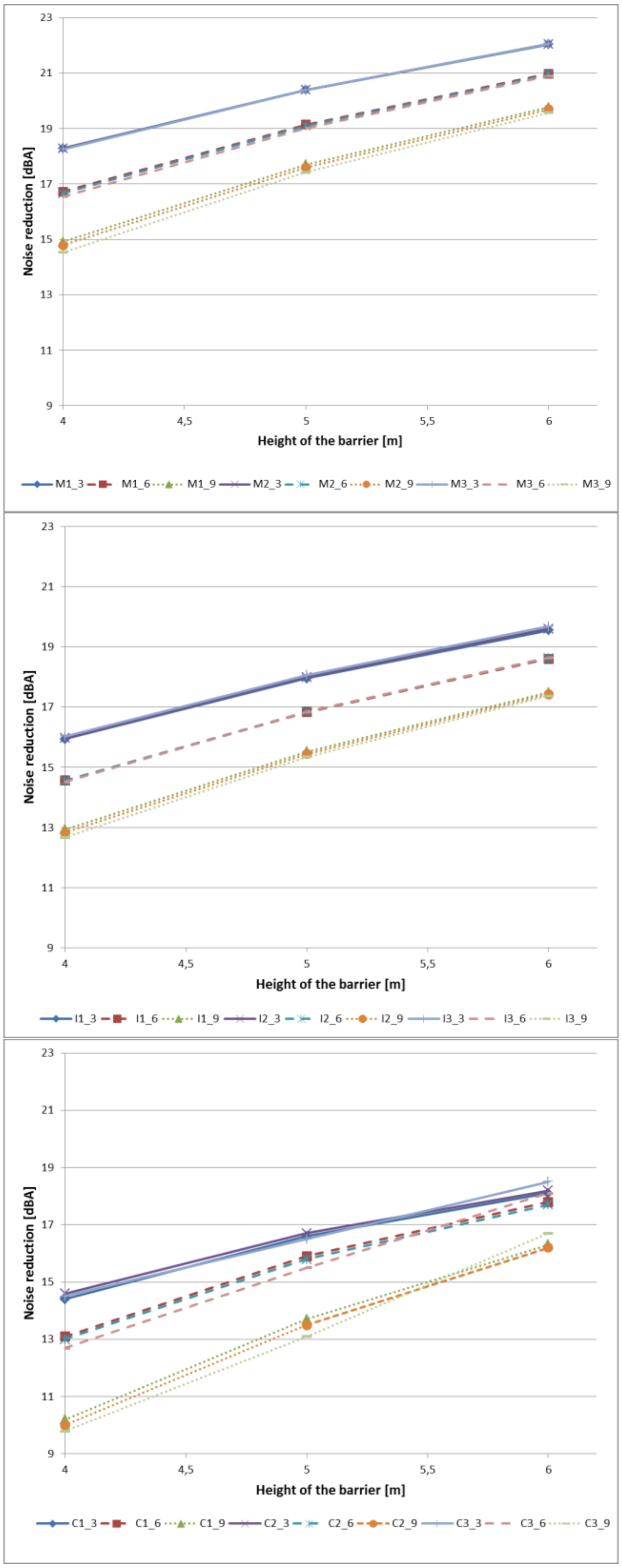

Fig. 9: Noise reduction plotted as a function of the height of the barrier (4, 5 and 6 meters), for buildings 1, 2 and 3. The lines are a guide to the eye. (Top) Maekawa, (Centre) ISO9613, (Bottom) CadnaA. Solid lines refer to the first floor (z=3m); dashed lines refer to the second floor (z=6m); dotted lines refer to the third floor (z=9m).

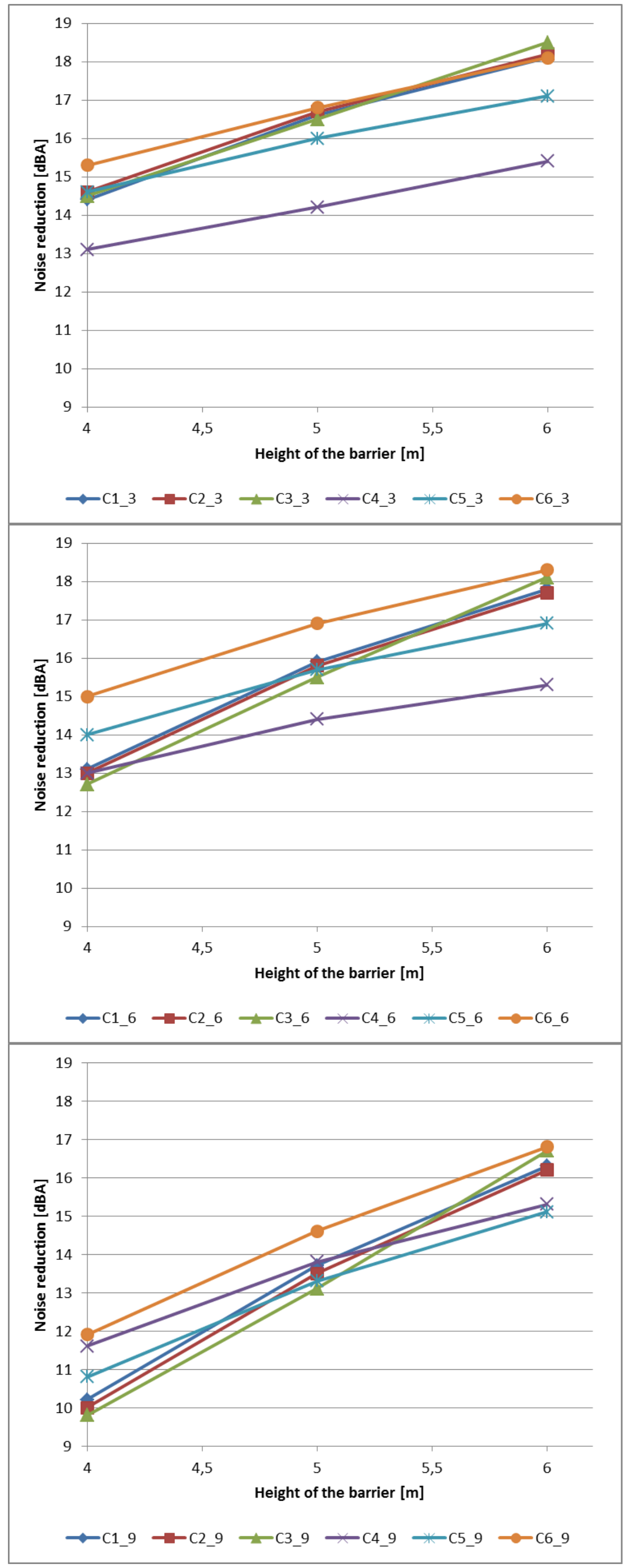

Fig. 10: Noise reduction plotted as a function of the height of the barrier (4, 5 and 6 meters), for all the 6 buildings, evaluated by CadnaA method. The lines are a guide to the eye. (Top) first floor (z=3m), (Centre) second floor (z=6m), (Bottom) third floor (z=9m).

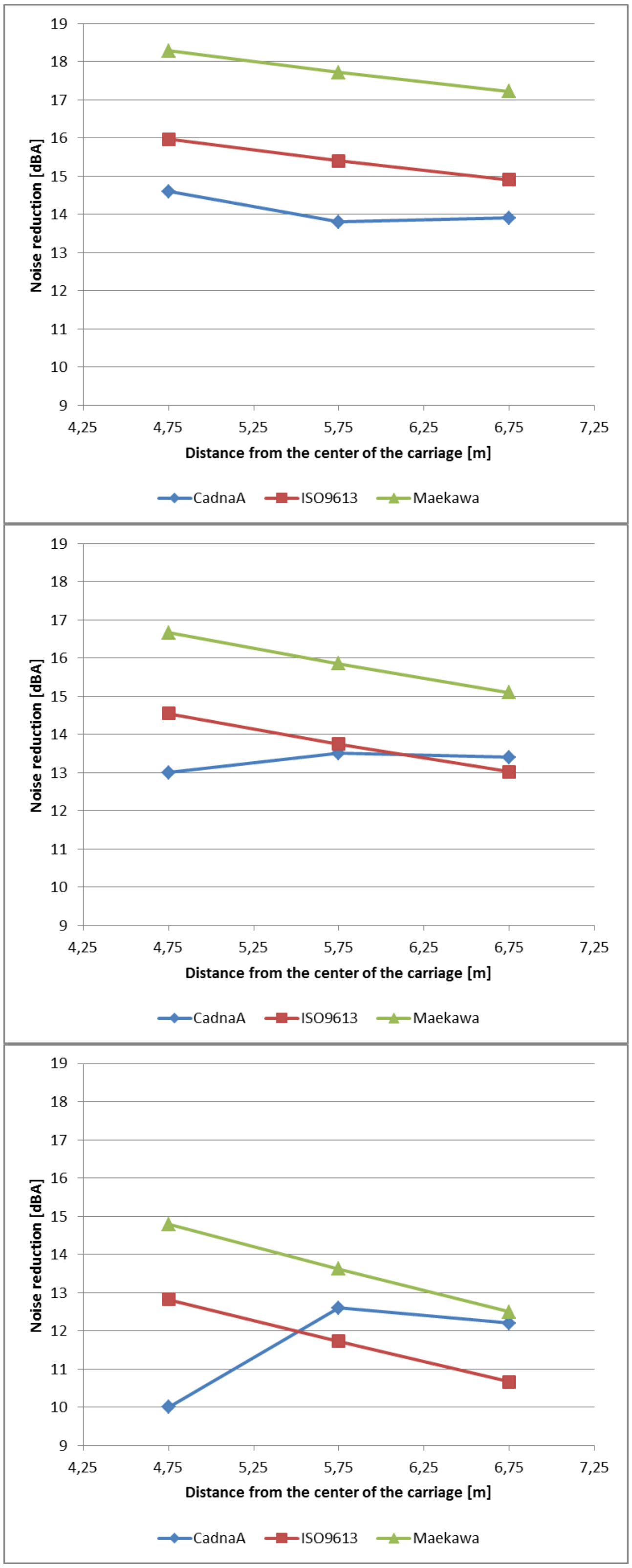

Fig. 11: Noise reduction plotted as a function of the distance of the barrier from the center of the carriage (4.75 , 5.75 and 6.75 meters), for building 2, evaluated by all the methods. The lines are a guide to the eye. (Top) first floor (z=3m), (Centre) second floor (z=6m), (Bottom) third floor (z=9m).

VI. Conclusions

In this paper, the noise reduction due to the insertion of an acoustical barrier is studied in terms of different calculation methods. A set of buildings built along a motorway in south Italy has been considered as a case study.

The noise map of the area has been calculated, with the aid of a predictive software, in presence and in absence of a sound barrier placed along the motorway. The effect of the barrier has been evidenced and quantified evaluating the noise reduction.

Results of attenuation obtained from literature formula (Maekawa), international regulation (ISO9613) and predictive software (CadnaA) have been compared, varying the height and the distance (from the centre of the roadway) of the hypothetic barrier. The differences between the three methods are present but not drastic. Maekawa's formula usually gave the highest value of barrier attenuation, due to the fact that it does not include ground, air and other absorption effects.

In particular, the height of the barrier has been varied from 4 to 6 m, obtaining, as expected, an increase of the attenuation in each floor. This is due to the increase of path to be covered by the sound ray. The distance from the centre of the carriage has been varied from 4.75 to 6.75 m, and the results showed that the closest the barrier is to the motorway, the highest the attenuation is. Only the predictive software showed a different behaviour for the upper floors, probably related to effects, for instance reflections from other buildings, not considered in the ISO9613 and Maekawa models.

Further applications of this study could be related to field measurement validation, in order to calibrate the software calculation and to test which methods is more reliable. The eventual results could be used to properly design the barrier that is going to be installed.

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