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Acoustic zoning of Chioggia, road traffic noise measurements and mathematical model

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The acoustic zoning of Chioggia (Venice) has been carried out taking into account the areas defined by the city plan, their densities of population, office buildings, shops, factories, and activities related to tourism. All the areas have been firstly assigned to the relevant acoustic classes according to the results of the statistical analysis. The resulting zoning has been verified by a survey and several changes occurred to be made in the acoustic classification.
In addition road traffic noise monitoring has been carried out for an entire week in eighteen different sites, representative of different urban configurations, where sound levels (continuous equivalent L_{Aeq} and percentiles L_N) were measured and, at the same time, number, type and speed of the passing vehicles were taken.
In other thirty-four sites, depending on the previous ones as far as the traffic flow concerns, measurements have been performed for fifteen minutes. Traffic flow data have been correlated with the hourly L_{Aeq} levels in order to develop a mathematical model.

1. INTRODUCTION

The acoustic zoning of Chioggia was carried out according to the Italian main Act on noise pollution 447/95. Located in the Venice district, the territory of Chioggia extends for 87 square kilometers and includes about 50.000 residents. The territory is formed by the towns of Chioggia and Sottomarina: the first is one of the most important Italian fishing trade harbours, the second is a popular holiday resort. The economy is based on horticulture, farming and, partially, on industry. The city is crossed by the state road n. 309 (Romea) and by three country roads. Road traffic noise measurements were also carried out in order to define strategies to reduce the noise in the city.

2. ACOUSTICAL ZONING

A digital drawing of the territory (in a .dwg file) was set up, where more than 1.200 areas defined by the city plan are delimited by polylines. The extension of each area was estimated by means of a CAD software. The data concerning the population (number of residents referred to each house in all the streets) were collected and the analysis of the waste-tax provided the data on trade, craft and tourist activities (surface of office buildings, shops, factories, tourist activities and corresponding codes). A spreadsheet was used to organize for each area the corresponding data, namely code, surface, usage according to the city plan, number of residents, surface of office buildings, shops, factories and activities related to tourism. The data collected for tourism were considered because this activity is peculiar for Sottomarina.

As first draft all the areas were classified into the second, third or fourth acoustic class according to the results obtained from the statistical analysis of the data collected, i.e. taking into account the road traffic, the population density, as well as the above mentioned economic activities. To determine the class corresponding to each area the density values were divided into three ranges (low, medium, high). However, because the data distributions were skewed towards low density values, it was thought not appropriate to divide the data range into either three intervals with equal width or using the mean value and the standard deviation. On the contrary, the boundaries of the low range were fixed at the minimum density and at 2/3 of the interval delimited by the minimum and the mean density, whilst the boundaries of the high range were fixed at 1/3 of the interval delimited by the mean and the maximum density and at the maximum density. Such a division does not depend on the number of areas included in each of the three ranges.

The zoning obtained by the statistical analysis was verified by a survey carried out in the territory. Since in several cases differences have been observed between the data used for the statistical analysis and the present situations, the survey, firstly planned to be carried out in a small amount of cases, has been extended to all the built-up areas. In addition, the survey enabled also to define the acoustic sensitive areas (schools, hospitals, ...) and the industrial areas. The final acoustic classification (Figure 1) includes also the areas near the roads and highways (30 or 60 meter depth) and railways (100 plus 150 meter depth).

It has to be pointed out that the classification based on the statistical analysis played only a preliminary role.

3. ROAD TRAFFIC NOISE MEASUREMENTS

3.1 Dominant positions

Examining the road network, 18 positions were selected, and called dominant because they essentially determine the traffic flows in the adjacent streets. With a view to develop a mathematical model, the noise measurements were carried out at a distance as close as possible to 7.5 m from the road centre line (where the noise source is considered to be at a height of 0.5 m). The microphone was located at a height of 4 m and, wherever possible, the distance between the microphone projection to the ground and the road centre line was 6.6 m, (actually the range was 3.2÷12.9 m, mean value 7.7 m and standard deviation 2.7 m).

The noise measurements were carried out on June, July and August to analyze the situation corresponding to the medium-maximum noise pollution. The monitoring was continuous for seven days and the equivalent levels L_{Aeq} were taken every minute and every hour. The statistical levels L_1, L_{10}, L_{50}, L_{90}, L_{99} were determined for every hour by the time history of sound pressure level in dB(A) Fast . The hourly equivalent levels were also processed to get daily and weekly day- (6.00 a.m.÷10.00 p.m.) and night-time (10.00 p.m.÷06.00 a.m.) levels.

The measurements of traffic flow were carried out nearby the dominant positions with four microwave sensors located at the edge of carriageway. For each lane the number and type of passing vehicle (bicycle, motorcycle, car, van, bus and truck, TIR) as well as the speed (0-30, 30-50, 50-70, 70-90, 90-110, > 110 Km/h) were determined for each hour.

3.2 Dependent positions

Thirty-four additional sites, called dependent, were selected in streets in the surroundings of the dominant positions. In these sites the microphone was located at the height of 4 m and the distance between the microphone projection to the ground and the road centre line was 6.6 m. The measurements were carried out for 15 minutes at day-time in hours characterized by medium or peak traffic flow, and when the continuous monitoring in the corresponding dominant position was in progress. This kind of survey enables to estimate the mean day-time values of the sound level (and of the traffic flow) for the dependent position, assuming the same temporal pattern detected in the corresponding dominant position.

The noise measurements taken for 15 minutes included the equivalent level L_{Aeq}, the statistical levels L_1, L_{10}, L_{50}, L_{90}, L_{99} as well as the 1/3 octave band (20÷20000 Hz) equivalent levels. For the same period the number, type and speed range of passing vehicles were manually monitored.

4. RESULTS OF THE MEASUREMENTS

Figure 2 reports an example of the sound level time history and of the traffic flow monitored in a dominant position. As regards the daily equivalent levels, they usually show small differences between day and night. The difference between the maximum and the minimum day-time level is less than 2 dB in 6 positions, it ranges from 2 to 4 dB in 10 positions and from 4 to 5 dB in 2 positions. In the night-time the above difference is less than 1 dB in 3 positions, it ranges from 2 to 4 dB in 11 positions and from 4 to 8 dB in 4 positions.

As regards day-time levels, Saturday and Sunday are not too much different from weekdays.

The weekly equivalent levels range from 63 to 76 dB(A) in the day-time and from 58 to 73 dB(A) in the night-time. These values are 6÷10 dB higher than those obtained in a similar survey carried out in Merano (Bolzano) where the mean levels ranged from 55 to 70 dB(A) in the day-time and from 49 to 63 dB(A) in the night-time [1].

The weekly levels at day-time are on average 3.7 dB higher than the corresponding ones in the night-time (standard deviation 1.2 dB, minimum and maximum difference 1.7 and 5.6 dB). Because for each acoustic class, with the exception of the industrial class, the difference between the day and night limits is 10 dB, for the sites included in the survey the night-time limit was always the most critical to be complied.

5. THE MATHEMATICAL ROAD TRAFFIC NOISE MODEL

A mathematical model of the road traffic noise was developed on the basis of the data monitored in the dominant positions, considering the same structure of that proposed in 1983 by the Institute of Acoustics of the National Research Council of Italy [2].

Because the hourly values of L_{Aeq} were not comparable as taken in different configurations, they were referred to the reference distance d_0 =6.6 m. The dominant positions were grouped into four different configurations: L-shaped (6 sites), U-shaped with (2 sites) and without pavé (5 sites), suburban high-speed road traffic sites (2 sites). For each type of site the hourly L_{Aeq} values have been gathered hour by hour after having verified that for each hour there were homogeneous traffic flow conditions.

In applying to road traffic noise the relationship between the hourly $L_{Aeq,h}$ and the i-th single event level SEL_i:

$$L_{Aeq,h} = 10 \cdot \lg\left(\frac{1}{3600}\sum_{i=1}^{n} 10^{SEL_i/10}\right) \quad \text{dBA} \qquad (1)$$

it is appropriate to consider the SEL for different types of vehicles. In this study three categories were considered, namely motorcycles (*m*), light vehicles such as cars and vans (*l*), heavy vehicles (*h*). Thus, from equation (1):

$$10^{(L_{Aeq,h}+10\lg 3600)/10} = \sum_{i=1}^{m} k_i + \sum_{j=1}^{l} k_j + \sum_{k=1}^{h} k_k + b \qquad (2)$$

where $k_{j,j,k} = 10^{SEL_{i,j,k}/10}$. From the linear regression (minimum squares method) of the hourly $L_{Aeq,h}$ levels (gathered according to the above mentioned criteria) and the corresponding number of vehicles for each category and type of site, using the expression (2) the coefficients $k_{i,j,k}$ and b were determined. For instance in Figure 3 the box plot of the SEL values obtained for the three categories of vehicles in the U-shaped sites is given.
From the distribution of the SEL values for each category of vehicle the mode was determined in order to take into account the most frequent traffic flow condition. The differences between these mode values were calculated referring to the light vehicles. From the comparison between calculated and measured values of $L_{Aeq,h}$, the following relationship for the L-shaped sites was obtained:

$$L_{Aeq,h} = 38.8 + 10\ \lg\left(1.5\ nm + nl + 6\ nh\right) \quad dBA \qquad (3)$$

where nm, nl and nh are the number per hour of motorcycles, light and heavy vehicles respectively.
Equation 3 was applied to the U-shaped sites with and without pavé and correction factors, referred to the L-shaped and asphalt configuration, have been obtained. This factor is equal to 1.3 dB for U-shaped sites and asphalt street and 2.8 dB for U-shaped sites and pavé street.
The correction factor for the suburban high speed road traffic sites was determined by the same procedure, obtaining a value of 3.3 dB. Considering the measured average speed of the vehicles in these sites (about 75 km/h), this value is in good agreement with the correction proposed by the IDAC-CNR model [2].
At last the mathematical model obtained is given by the equation

$$L_{Aeq,h} = 38.8 + 10\ \lg\left(1.5\ nm + nl + 6\ nh\right) - 10\ \lg\left(d/d_0\right) + \sum_i \Delta L_i \quad \text{dBA} \qquad (4)$$

where $\sum_i \Delta L_i$ is the sum of the correction factors (1.3 and 2.8 dB for the U-shaped sites with and without pavé respectively; 3.3 dB for the suburban high speed road traffic sites).
The correlation coefficients between the $L_{Aeq,h}$ measured and those calculated by the model (4) are good: 0.93 for the L-shaped sites, 0.92 for the U-shaped sites without pavé, 0.84 for the U-

shaped sites with pavé and 0.83 for the suburban high speed road traffic. The differences between the measured and calculated $L_{Aeq,h}$ levels are satisfactorily low: mean of absolute values 0.9÷1.2 dB.
Thus the structure of the model proposed by IDAC-CNR [2], on which the present analysis is based, is suitable also for processing data collected by measurements carried out in real conditions, as Cocchi et al. verified too.

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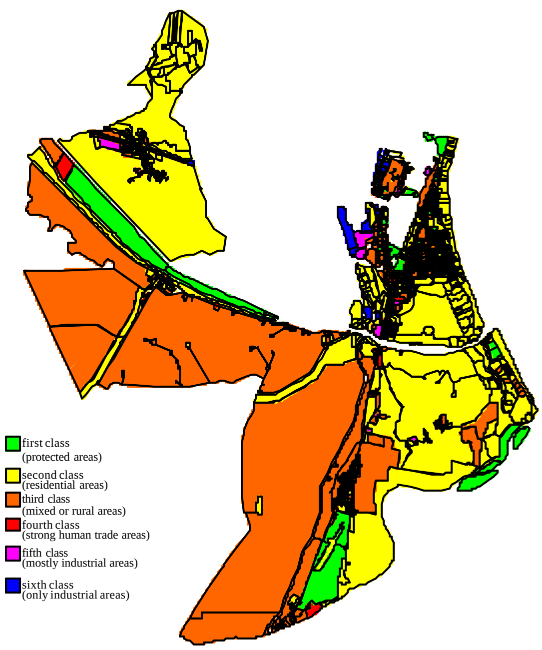

Figure 1. *Acoustical zoning of Chioggia*

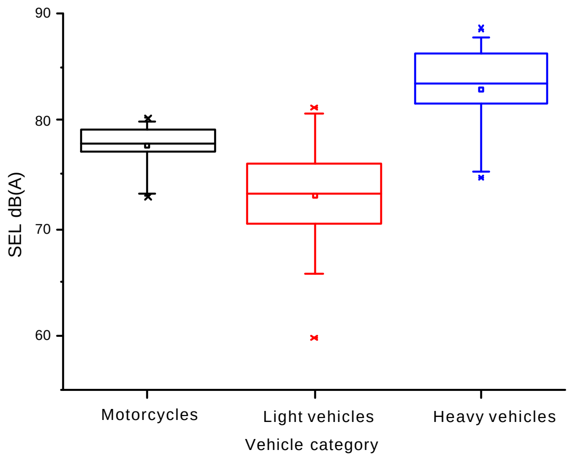

Figure 3. *Box plot of the SEL values obtained from (2) for U-shaped sites*

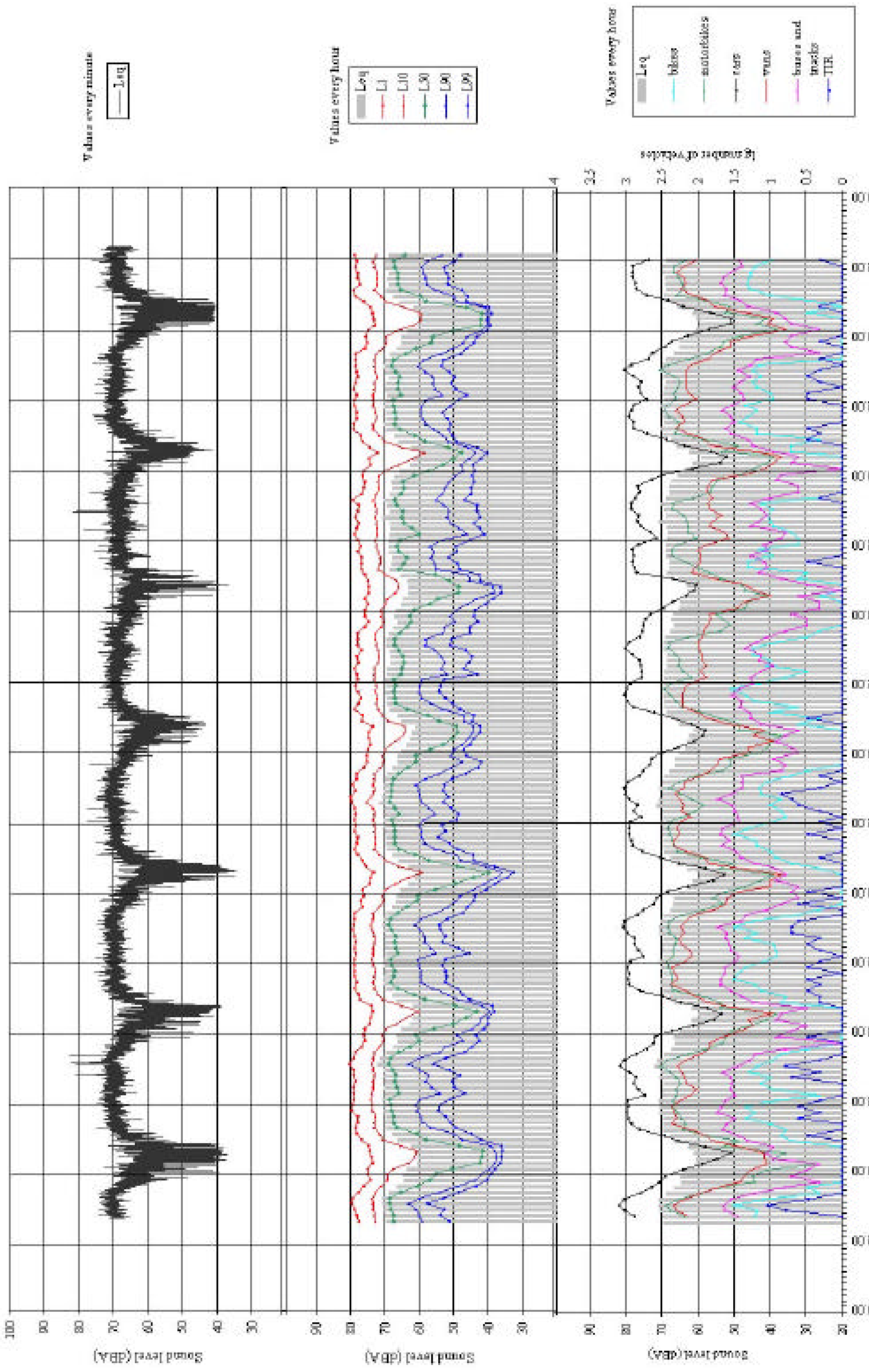

Figure 2. *Time histories of the sound levels and traffic flows monitored in a dominant position*