Experimental investigation of the effect of roundabouts on noise emission level from motor vehicles

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Roundabouts can provide benefits in many ways. They are safer, more efficient, less costly and more aesthetically appealing than standard at-grade intersections (controlled and signalized). The administrations have often identified roundabouts as a proven safety countermeasure for the following reasons: a) reduce overall conflict points and remove left-turn conflicts; b) reduce the vehicle speeds; and c) reduce accident severity for all users, allow safer merges into circulating traffic, and provide more time for all users to detect and correct their mistakes or the mistakes of others due to lower vehicle speeds. Also, from an operational point of view, roundabouts offer the following significant advantages: a) may reduce delays and queues than other forms of controlled intersections; b) can reduce lane requirements between intersections, including bridges between interchange ramp terminals; and c) create possibility for adjacent signals to operate with more efficient cycle lengths where the roundabout replaces a signal that is setting the controlling cycle length. Furthermore, roundabouts can provide important environmental benefits reducing delays and the number and duration of stops. Even in heavy traffic, vehicles keep moving in the queue rather than coming to a complete stop. This may reduce significantly noise and air quality impact as well as fuel consumption by reducing the number of acceleration/deceleration cycles and the time spent idling. In this article, the environmental aspects associated with roundabouts are treated with reference to issues related to noise production. The experimental investigation will refer to a heterogeneous succession of intersections (standard intersections, two-way stop-controlled and roundabouts) characterized by homogeneous traffic flows. The results of the research are interesting and contribute to consolidate the awareness, already highlighted by other international studies, of the role of roundabouts as effective measures to mitigate traffic noise.

Primary subject classification: 13.2; Secondary subject classification: 72.1

1 INTRODUCTION

The reasons why many transit and highway administrations have often chosen roundabouts instead of standard at-grade intersections are related to traffic congestion reduction and improvement of safety (i.e., reduction of conflict points, decrease in approach speed, etc.), as confirmed by numerous international researches (e.g., Distefano et al.[1]; Distefano and Leonardi[2]).

Moreover, there are other positive effects provided by roundabouts, such as the reduction of air pollution and acoustic emissions. In particular, the effect of roundabouts on traffic noise is mostly due to changes in speed and driving pattern. The influence of roundabout geometry on noise reduction is less significant, although not negligible. Geometric characteristics only become relevant if roundabouts that differ considerably in size and number of arms are compared: the radius of the roundabout influences the length of the circulatory roadway and, therefore, the extension of the sections traveled in acceleration and braking which are critical points from an acoustic perspective; moreover, a high number of confluent arms could generate saturation and therefore a higher noise level.

In this article, the authors want to demonstrate through an experimental survey that roundabouts can actually be considered effective measures for noise reduction.

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By comparing the acoustic parameters (L_{Aeq}, L_5, L_{10}, L_{90}, L_{95}, L_{min}, L_{max}) detected near different types of at-grade intersections (stop-controlled intersections and roundabouts), it has been possible to highlight the advantages of roundabouts in terms of lower noise emissions.

The survey methodology adopted is the classical method of assessing acoustic parameters through phonometric measurements performed in different contexts and comparing them. The key feature of this research is that the four intersections selected for the investigation are all located along the same urban route and characterized by similar traffic flows both along the main arms and along the secondary ones, as shown by the traffic data detected during the same time intervals in which the acoustic measurements were taken. The intersections, moreover, have similar dimensions and the same number of arms. The two roundabouts examined, however, have different shapes: the first has a perfectly circular shape, and the second resembles an hourglass or peanut shape.

The survey results of the noise measurements, therefore, will be referred to nodes of the road network "homogeneous" from the point of view of traffic flows and types of users (they are usual drivers for the urban contexts analyzed) but "heterogeneous" for the approach method and for the kinematic conditions imposed by geometric conformations and regulation of the vehicular flows, totally different from each other (the rules of priority imposed by the stop signs in the case of standard at-grade intersections, and the rule of the "modern roundabout" or of the "priority to the left" in the case of roundabouts).

2 LITERATURE REVIEW

The traffic circulation on the elements composing the urban road infrastructures (nodes and arcs) is considered an important source of noise pollution. The effect on noise and on annoyance is highly dependent on traffic composition and speed, road layout and the use of individual measures such as road humps, chicanes, gateways, and roundabouts[3–5], as well as on how they are accepted by the drivers[6]. Generally, the effect of traffic calming measures on noise reduction consists in a decrease of up to about 4 dB of the equivalent sound level (L_{Aeq}) and up to about 7 dB of the maximum sound pressure level (L_{Amax})[5,6].

The analysis, assessment and estimation of noise levels in the vicinity of intersections are a more complex problem than a similar analysis for roads and streets. This is due to the varied geometry of the intersections, differences in the loads of individual movements, and participation of heavy good vehicles, as well as the various types of traffic management and traffic control. In the literature, there are several studies that evaluate the effects, in terms of noise emissions, of the different types of intersections (standard and roundabouts). It is largely accepted that converting a crossroad into a roundabout will decrease the noise level[7–11]. Berge[12] shows that L_{Aeq}-levels are 1–2 dB (A) higher at crossroads than at roundabouts, even if the average speed is the same. In many studies, it is shown that replacing a signalized intersection with a roundabout, under certain conditions, may reduce traffic noise [13–18]. Gardziejczyk and Motylewicz[19] have shown that, with comparable traffic parameters and the same distance from the geometric center of the intersection, the L_{Aeq} value for signalized roundabouts is 2.5–10.8 dB higher in comparison to classic signalized intersections and 3.3–6.7 dB higher in relations to the unsignalized roundabouts. Additionally, the differences between L_{Aeq} levels at individual entries at the same signalized roundabouts may reach the value of approximately 4.5 dB. This situation is influenced by differences in the intersection geometry, diameter of the intersection's central island, traffic flow type, traffic management at the entries and traffic flows, especially the amount and traffic movements of multiple axle heavy good vehicles.

Moreover, it is well established that roundabouts produce less annoying noise than signaled-controlled intersections. This outcome may be explained by differences in traffic flow dynamics: at signal-controlled intersections, traffic flows resembled a constant pulsed flow, with alternate cycles of acceleration/deceleration at roundabouts; instead, the traffic flow was more similar to a constant fluid flow, with less marked cycles of acceleration/deceleration. Sound unpleasantness at roundabouts increased only with the presence of heavy good vehicles or buses[20].

Although roundabouts can carry smooth traffic flow by minimizing the start-stop operations of drivers, the noise emitted from moving vehicles would definitely affect those people who live, work, or study in the vicinity.

The prediction of traffic noise near roundabouts has attracted wide attention, and many prediction models and methods have been proposed[6,21]. However, noise levels are strongly influenced by the complex vehicle interactions taking place at the entries. Therefore, an accurate modeling of the merging process and its impacts on vehicle kinematics, waiting time at the yield signs and queue length dynamics is required. A way to capture all traffic dynamics impacts on noise levels consists in combining a traffic simulation tool with noise emission laws and a sound propagation model[22,23]. In particular, the dynamic noise emission model proposed by Chevallier et al.[23] fills the shortage of accurate noise estimation procedures at roundabouts. The noise emissions due to stochastic vehicle interactions at roundabouts entries can be fully captured by combining a microscopic traffic flow model with noise emission laws and propagation calculation. Contrary to other existing noise simulation packages, the merging process and its impact on kinematics, vehicle delays and queue lengths are accurately reproduced for any traffic conditions. The traffic outputs are fed into relevant noise emission laws depending on the vehicle type and the prevailing road pavement type. An instantaneous noise power level can be calculated for each vehicle from vehicle speed and acceleration. These levels are input into a propagation model to compute the noise levels received at different points in the vicinity of the roundabout. Accuracy of the obtained noise contour maps was demonstrated by comparing the simulated and the observed noise pressure levels at several receivers along a suburban roundabout.

Picaut et al.[24] propose to study roundabouts by coupling an acoustic modeling of passenger cars with a typical kinematics signature and trajectory of the car around the roundabout. The acoustic emission is based on an equivalent source modeling, including acceleration and deceleration phases, while the traffic flow conditions are measured on real roundabouts. Measurement comparisons for two roundabouts are proposed and show consistent results. Moreover, it is shown that this simple model can be used to estimate the noise impact of a roundabout, in comparison with a straight road.

To and Chan[21] present an analytical solution of the noise emitted from vehicles at roundabouts by assuming vehicles to be incoherent sources lying continuously on the roundabouts. A simple equation is introduced which allows to relate the noise level at any distance from the center of the roundabout to the noise level measured at the center of the roundabout.

3 METHODOLOGY

The aim of comparing noise generated by the motorized vehicles while crossing roundabouts, with that generated at standard intersections, was pursued through the following procedure:

- choice of adequate sites for the purpose of the survey;
- evaluation of acoustic parameters through a phonometric survey;
- estimation of traffic flows through manual survey;
- elaboration of the acquired data and exposure of the obtained results.

The first three points of the abovementioned procedure will be described in Sec. 3.1 and 3.2. The presentation of the results and their interpretation will be described in detail, with the support of various explanatory diagrams, in Sec. 4.

3.1 Location and Characteristics of the Intersections

An experimental survey was conducted in a suburban road environment to assess the noise produced at intersections. The survey was carried out at a series of intersections located in Aci S. Antonio (CT), an Italian town, characterized by the presence of a ring-road that delimits the urban center and connects to the provincial road network through two different types of road nodes: standard at-grade intersections and roundabouts.

It should be noted that in recent years the town administration has adopted the policy of transforming the intersections on the ring-road into roundabouts, with the aim of easing traffic entering and leaving the urban center and toward other destinations.

At present, this transformation is only partial. This implies the presence of an alternation of roundabouts and standard intersections that allows a comparison of the noise production between these two design solutions.

The ring-road is a suburban road, while the roads that converge on it are neighborhood streets and urban streets. Table 1 summarizes the main characteristics of the roads investigated.

The road surface is in average/good condition, and it remains homogeneous throughout.

The context analyzed is predominantly suburban, and therefore there is a significant presence of residential and commercial buildings; this implies the existence of numerous accesses near the main road, especially near the intersections. However, entering traffic from the accesses is

Table 1—Characteristics of the roads investigated.

	Italian road classification according to the D.M. 5/11/2001. “Functional and geometric rules for road construction.” G.U. N.3, 04/02/2002		
	C (secondary suburban roads)	E (neighborhood streets)	F (urban street)
Design speed	60÷100 km/h	40÷60 km/h	25÷60 km/h
Type of cross-section	Single carriageway, consisting of two lanes of 3.50 m in each direction	Single carriageway, consisting of two lanes of 3.00 m in each direction	Single carriageway, consisting of two lanes of 2.75 m in each direction
Width of the shoulders	1.50 m	0.50 m	0.50 m

significantly lower than the traffic on the main roads, and its contribution in terms of equivalent sound level is to be considered negligible.

Moreover, from an acoustic point of view, no particular sources of noise were found in the area, except those due to occasional phenomena which, in any case, did not influence the evaluations of the equivalent sound levels relative to the different hours of the survey.

For the experimental analysis, 4 intersections were chosen (2 standard at-grade and 2 roundabouts) located in sequence in the south-east area of the ring-road and affected by a very high traffic volume. As shown in Fig. 1, there is a sequence of intersections composed of two roundabouts located at the two ends and two standard crossroads placed inside.

3.2 Acoustic and Traffic Measurements

The experimental investigations aimed at the acoustic characterization of the intersections described above were carried out in the months of April and May, on weekdays excluding Mondays and Fridays because they are close to the weekend. The noise measurements have been carried out in the absence of rain and fog and with wind speed always less than 5 m/s.

Two Larson & Davis 700 sound level meters, compatible with the class 1 precision (rounding to 0.5 dB) and complete with calibration certificate, were used for the acoustic measurements.

The microphones mounted on each of the sound level meters are of random incidence, class 1, equipped with windscreens.

The phonometric measurements were performed with the weighting curve A and with the FAST time constant, in order to obtain a rapid response to the fluctuations of the sound waves.

Calibration of the equipment was performed before and after each measurement cycle.

Since the objective of this research is to compare the noise induced by the traffic regulated by two types of intersections for how they affect the dynamics of the motion, it was decided to organize the acoustic survey in order to evaluate the noise induced by the road environment as a whole, including both traffic and the type of intersection

Fig. 1—Location of the intersections investigated (ring-road around Aci S. Antonio).

(standard or roundabout). In particular, the sound level meters have always been placed, both for the standard intersections and for the roundabouts, at a distance of about 10 m from the axis of the lane closest to the measurement section, in order to be sufficiently far from the main road and to consider above all the contribution to noise by traffic flows on minor arms of the road intersections; this positioning of the measuring instrument was considered appropriate in order to evaluate the variation in noise levels due to the different dynamics of vehicle motion induced by the two traffic regulations typical of the intersections analyzed: a) two-way stop controlled intersections and b) roundabouts (priority to the left). In this way, the appropriate condition was obtained to ensure that the sound level meter measured noise under very similar conditions for vehicle flow rates but different in relation to the following dynamics of motion in intersection areas:

- frequent stop and go phenomena for standard intersections;
- mainly fluid vehicle flow conditions for roundabouts.

Figure 2 illustrates, for each of the 4 intersections examined, the measurement sections in which the sound level meters have been installed. In particular:

- the measurement sections at the standard intersections were positioned on the central island, about 10 m from the main road axis (D_A = 10.20 m; D_B = 10.00 m);
- the measuring sections at the roundabouts were chosen within the central island, about 3–4 m from the edge (D'_C = 4.10 m; D'_D = 3.30 m) and at a distance of 9/10 m from the axis of the circulatory roadway ($D_C = D'_C + W_C = 9.60$ m; $D_C = D'_C + W_C = 9.10$ m). The sound level meter was oriented toward the circulatory roadway portion which guaranteed the best operating conditions (distance from noise sources and reflecting surfaces).

Moreover, in this type of survey, the position of the microphone for homogeneous road sections is irrelevant, since the variations of noise at one point are reflected evenly on all the other points of the same section. Therefore, the height from the ground of the microphone has been kept constant to ensure consistency between the detected data. As suggested by the Italian Standards (DM 16/3/98, "Sound detection and measurement techniques"), the measurements were carried out at a height of 1.5 m above the ground level. In this way, the influence of possible sound reflections induced by the road surface was also considered, thus considering all the sound sources that are part of the road environment object of the survey. The 1.5 m height has also allowed to consider the sound impact on users typical of urban areas such as cyclists and pedestrians.

During the overall survey period, 256 noise measurements, each lasting 1 hour, were recorded in order to fully characterize the sound level at each intersection for the 16-hour daytime period (from 6.00 to 22.00) defined by the Italian law (DPCM, 1/03/91, "Maximum limits of exposure to noise in living environments and in the external environment"; Law 447/95, "Framework law on noise pollution").

It is evident that the time data necessary for the determination of the diurnal periods relating to the four intersections are in a number equal to 64. However, a four-fold analysis sample has been chosen for the following reasons:

- to exclude measures affected by errors (due to incorrect positioning of the sound level meters, inaccuracies in the settings of the instruments and any other cause);
- to eliminate data related to uncompleted measurements due to the exhaustion of the power supply;
- to identify univocally measures distorted by particular sound sources;
- to have a statistically significant sample of available measures.

The repetitions of the hourly measurements were performed cyclically: for each of the intersections, the noise measurements corresponding to the same time interval (e.g., 6.00–7.00) were performed in 4 different days (e.g., Tuesday, Wednesday, Thursday, Tuesday). In this way, each time interval was always evaluated in each of the 3 useful days (Tuesday, Wednesday, Thursday) and was further evaluated in one (and only one) of the possible days of the survey.

The acoustic parameters that were evaluated as a result of the phonometric measurements are as follows:

- Minimum and maximum sound pressure levels (L_{min}, L_{max});
- Equivalent sound level (L_{Aeq});
- Cumulative statistical levels (L_5, L_{10}, L_{90}, L_{95}); in this specific case, we assessed L_5, L_{10} (peak noise), L_{90}, and L_{95} (background noise).

During the same time interval of the noise measurements, a series of traffic surveys were organized as follows:

- Five measurement sections were chosen, placed between one intersection and the other, on the main road (ring road) to obtain information on the variation of traffic flows due to the presence of the four consecutive intersections;

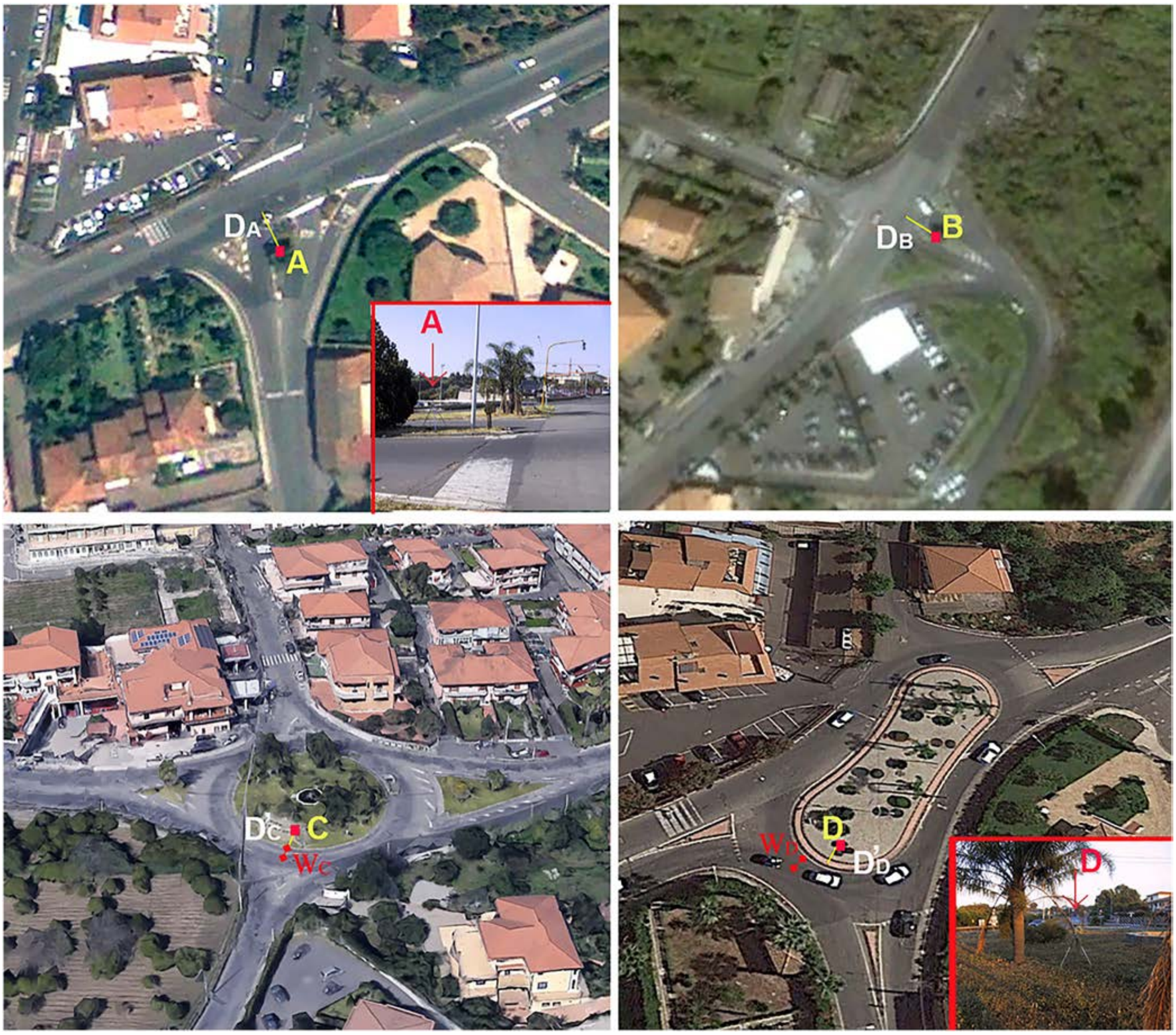

Fig. 2—Arrangement of sound level meters at standard intersections and roundabouts: reference distances for measurements (DA, DB, D′C, D′D, WC, WD).

- A further pair of measuring sections were identified at each of road intersections corresponding to each of the secondary branches;
- A team of 3 operators, proceeded to manually annotate on a paper form the traffic flows for each direction divided into 3 categories (cars, heavy good vehicles, motorcycles and mopeds).

It should be noted that the traffic data were obtained for the number of hours (64) necessary to define the traffic conditions associated with each of the analysis period of each surveyed intersections. Also, in this case, the 3 operators carried out the cyclical measurement activity, spreading the data acquisition over several weeks and obtaining the traffic flows relative to each of the 64 reference hourly intervals.

It is important to note that for the execution of traffic counts, in line with the widely established practice of traffic surveys, traffic conditions in the three central days of the week (Tuesday, Wednesday and Thursday) were considered homogeneous. This obviously leads to discrepancies in traffic flows detected in the 3 days considered. Repeating counting over several weeks helps reduce the error but does not eliminate it. The fact that the execution of traffic surveys with manual methods is burdensome and complex required this staggered mode of vehicle traffic counting operations which is not rigorous but is nevertheless very reliable for the purposes of characterizing the prevailing traffic conditions in the road intersections.

For the purposes of the elaborations that will be discussed in Sec. 4, the following two parameters associated with traffic flow conditions have been taken into consideration:

1. Hourly vehicular flow (Q): this represents the total number of vehicles that maneuver at the intersection in the time interval considered, without distinction between the three vehicle categories (cars, heavy vehicles, motorcycles and mopeds). In particular, Q is calculated with the following equation:

$$Q = Q_{car} + Q_{HV} + Q_{MM} \qquad (1)$$

Where:

- Q_{car} = passenger cars flow (veh/h);
- Q_{HV} = heavy good vehicle flow (veh/h);
- Q_{MM} = mopeds and motorcycles flow (veh/h);

2. Acoustically equivalent hourly traffic flow (Q_{eq}): this is a parameter, specifically defined and introduced in this research, which represents the number of vehicles located at the intersection, weighted according to the acoustic equivalence of the three vehicle classes. In particular, Q_{eq} is evaluated with the following equation:

$$Q_{eq} = f_{car} \cdot Q_{car} + f_{HV} \cdot Q_{HV} + f_{MM} \cdot Q_{MM} \qquad (2)$$

Where:

- Q_{car} = passenger cars flow (veh/h);
- Q_{HV} = heavy good vehicle flow (veh/h);
- Q_{MM} = mopeds and motorcycles flow (veh/h);
- f_{car} = acoustic equivalence factor for passenger cars; it is equal to 1.
- f_{HV} = acoustic equivalence factor for heavy good vehicles; it is equal to 8 (the choice of the value 8 is derived from the equivalence factor indicated in the forecast model of Cannelli, Gluck and Santoboni[25]. This model is used as a reference in the Italian technical standards);
- f_{MM} = acoustic equivalence factor for mopeds and motorcycles. It is equal to 5 (the choice of the value 5 is derived from the study on the acoustic equivalence factors of mopeds and motorcycles published by Leonardi[26]).

4 RESULTS AND DISCUSSION

The variation of the acoustic parameters in the reference time interval (16 hours), relative to the four surveyed intersections, is shown in the diagrams in Fig. 3, Fig. 4, Fig. 5 and Fig. 6. From the analysis of these diagrams, the following observations can be made:

- There are similar values of the background noise level at almost all intersections. Parameter L_{95} averages around 55 dB, except for the intersection 2 on which, due to the noise coming from the nearby highway, values of L_{95} were about 4 dB higher.
- The peak noise is significantly different depending on the type of intersection. At roundabouts, L_5 has average values around 70 dB, while the standard intersections have L_5 values 4–5 dB greater than the roundabouts L_5 values.

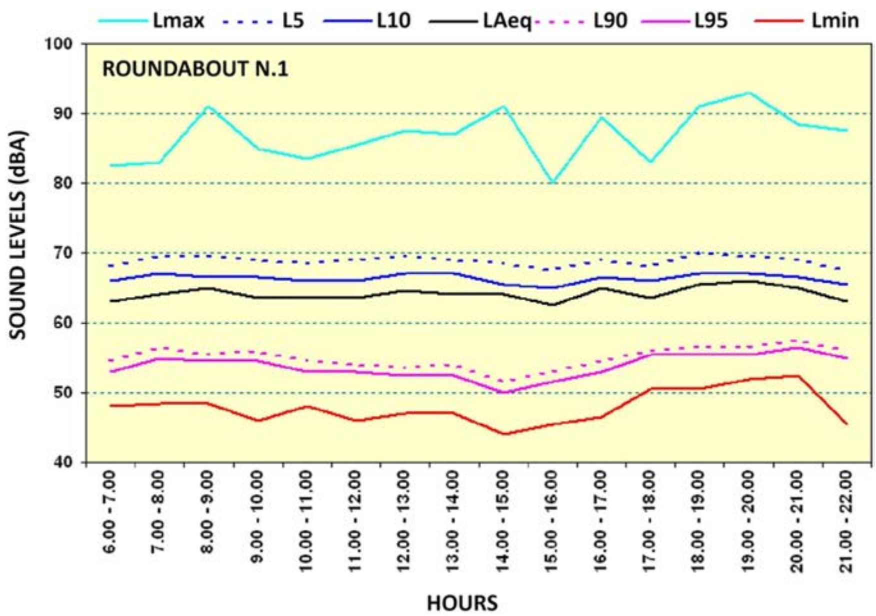

Fig. 3—Acoustic parameters' trends for roundabout N.1.

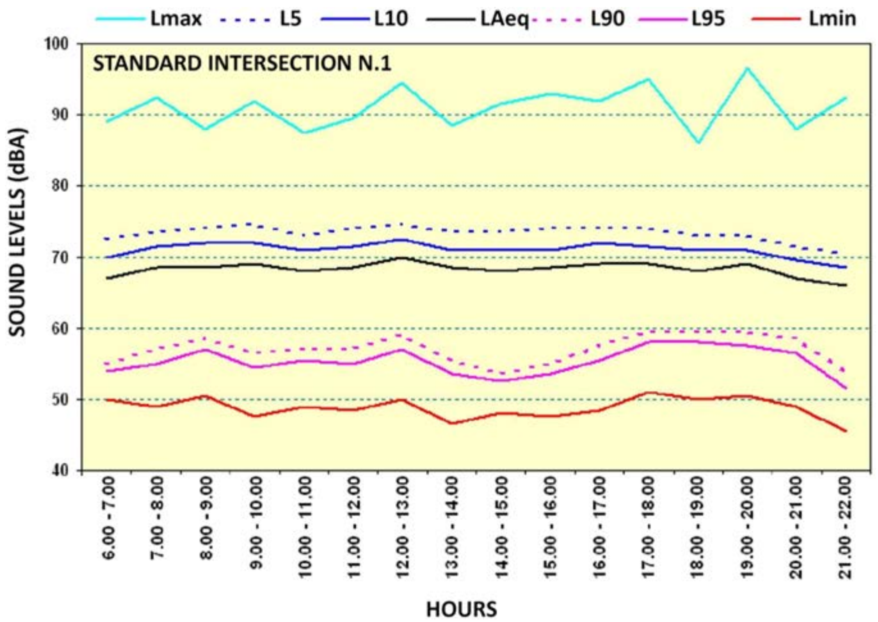

Fig. 4—Acoustic parameters' trends for standard intersection N.1.

- In case of L_{min} and L_{max}, similar considerations can be made to those reported in the previous points. In fact, the values of L_{min} are almost identical for all the intersections (with the sole exception of intersection 2), while the L_{max} values found at the standard intersections are 4–5 dB higher than those measured at the roundabouts.

The noise mitigating effect of roundabouts is then confirmed by the analysis of equivalent sound levels. From the diagram shown in Fig. 7, it can be seen how the values of the L_{Aeq}, during the time interval of 16 hours, on the roundabouts, are variable within a range of approximately 63 dB to 66 dB. The corresponding values at the standard intersections vary between 67 dB and 70 dB.

The diagrams shown in Fig. 8, Fig. 9, Fig. 10 and Fig. 11 show, for each intersection and for the reference time interval, the relationship that exists between the traffic flows, both in their classical expression and with reference to the acoustically equivalent traffic flows defined in this research, and equivalent sound levels.

The observation of these diagrams confirms that the production of noise at road nodes is mainly conditioned by the approach to the different types of intersections and therefore by the kinematics of motion (in terms of speed and acceleration). In fact, traffic flows are very similar for

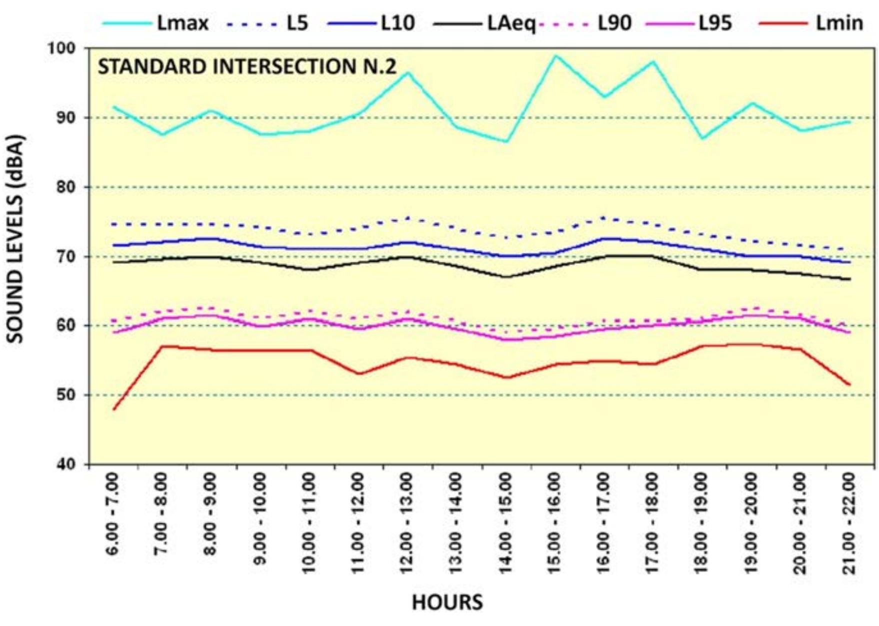

Fig. 5—Acoustic parameters' trends for standard intersection N.2.

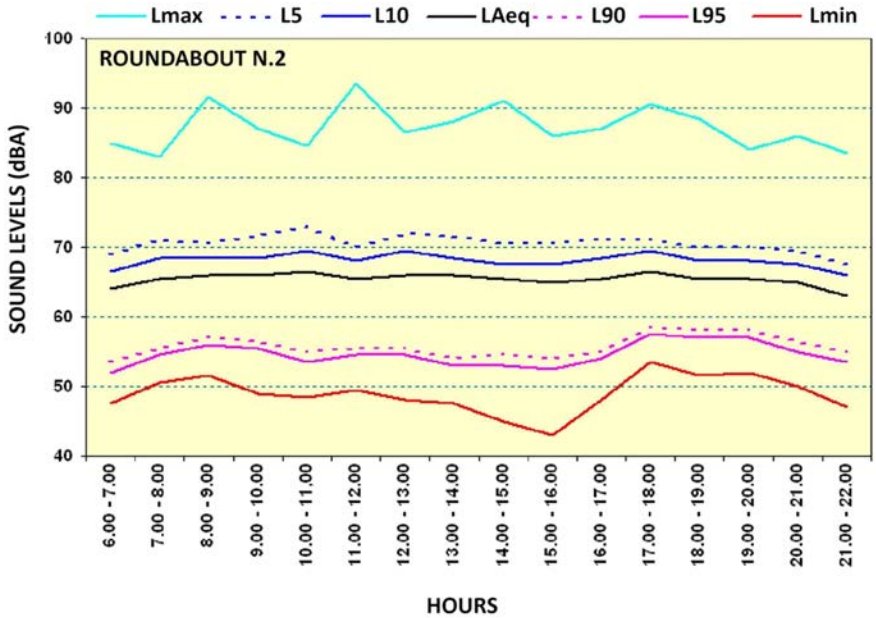

Fig. 6—Acoustic parameters' trends for roundabout N.2.

both roundabouts and standard at-grade intersections. The differences between the traffic flow values at the four intersections, in Figs. 8, 9, 10 and 11, are due to the operations of counting the traffic flows which, as explained above, have been staggered and carried out not simultaneously on the road intersections examined. Instead, the differences between the sound levels measured at the two types of intersection are significant. This means that roundabouts originate an attenuation of the noise, under the same traffic conditions since they favor both the reduction of the approach speed and the fluidification of the circulation to the detriment of the stop and go phenomena typical of the other types of intersections.

From the analysis of the diagrams of Fig. 8, Fig. 9, Fig. 10 and Fig. 11, also it is then possible to obtain a further interesting consideration, not entirely obvious: the oscillations of the values of the equivalent sound level are strongly linked to the traffic flows. In fact, the peak values of the LAeq correspond to peak values of the traffic flow and vice versa; similarly, low traffic conditions correspond to the lower sound levels. The diagram in Fig. 12 helps to better understand the observations just

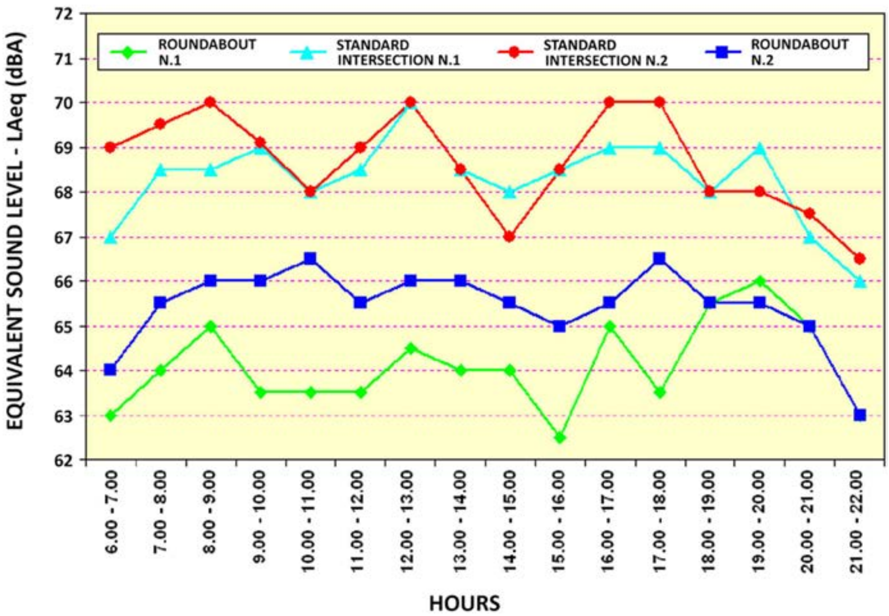

Fig. 7—Variation of the equivalent sound level, during the time interval of 16 hours, for the investigated intersections.

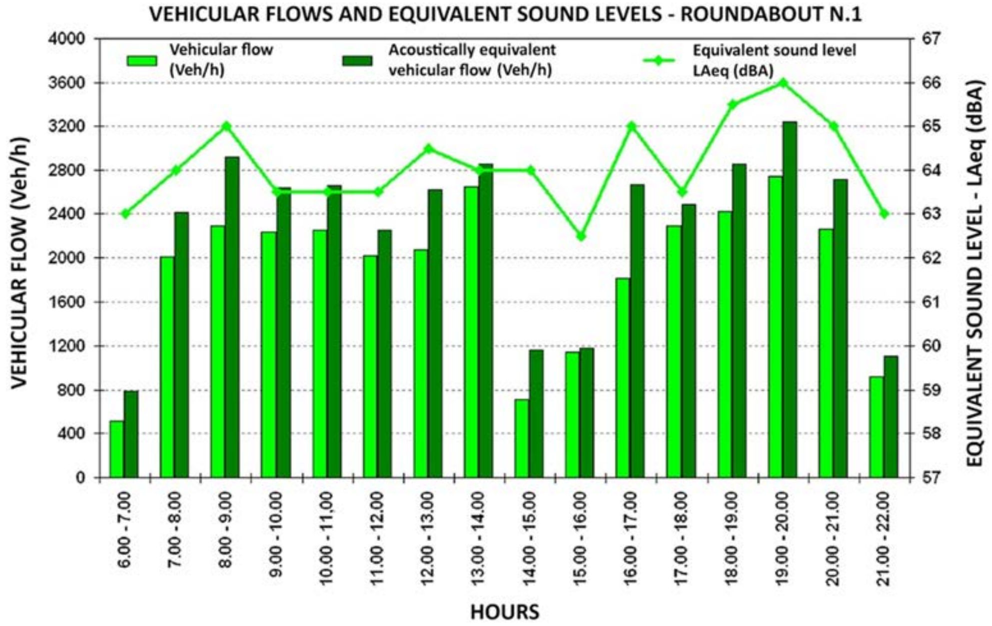

Fig. 8—Relation between vehicular flows and equivalent sound levels for roundabout N.1.

made. In fact, the variation of the sound level equivalent in relation to the variation of the acoustically equivalent traffic flow, for each of the four intersections investigated, is reported. There are also the curves (straight lines) that fit the points obtained from the experimental investigation. From the analysis of the diagram of Fig. 12, it is possible to deduce the following:

1. The equivalent sound level increases with increasing traffic flows with a similar trend for all four intersections analyzed. In fact, it can be noted that the slope of the straight lines that fit the experimental trend is always positive, practically identical in all four cases (0.008). The slope is slightly higher and equal to 0.009 only for the intersection 1.
2. The values of the intercepts — equal to 66.29 for the standard intersection N.1, 66.76 for the standard intersection N.2, 62.06 for the roundabout N.1 and 63.68 for the roundabout N.2 — show that the standard at-grade intersections originate values of the equivalent sound level averagely higher than about 3–4 dBA than roundabouts.

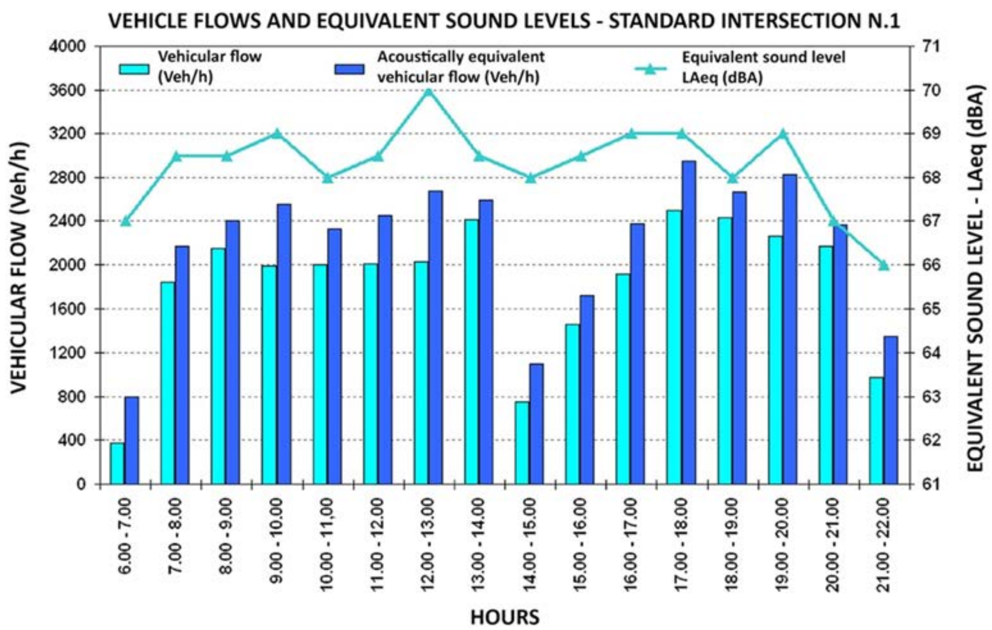

Fig. 9—Relation between vehicular flows and equivalent sound levels for standard intersection N.1.

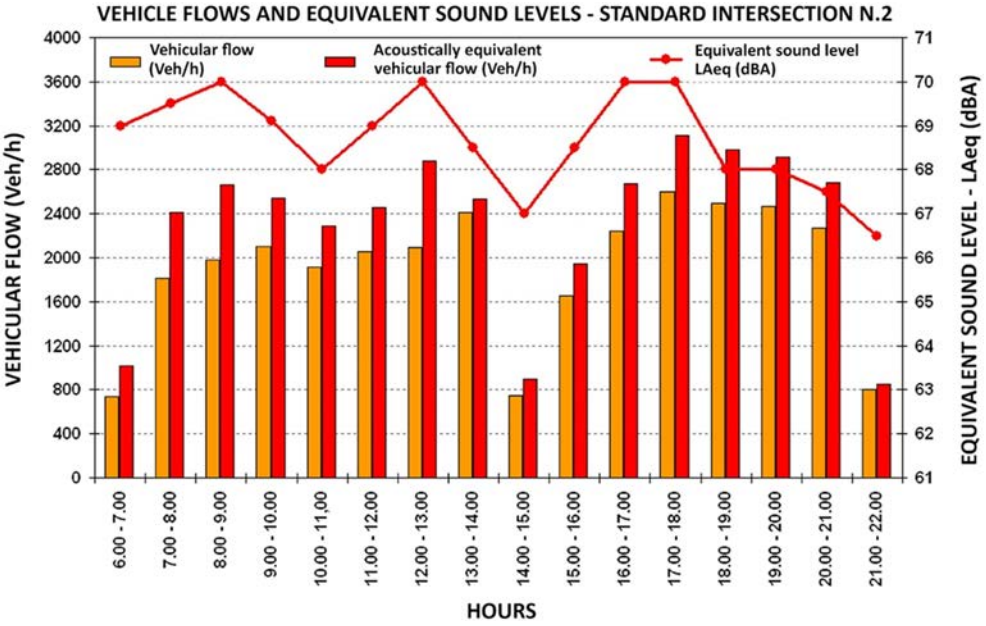

Fig. 10—Relation between vehicular flows and equivalent sound levels for standard intersection N.2.

Finally, it is considered important to compare the values of the equivalent sound level referring to the entire period of 16 hours which, as already mentioned, represents the time interval at which the Italian Standards refer for the quantitative assessment of diurnal noise pollution.

As is known, the equivalent sound level extended to the diurnal period, $L_{\mathrm{Aeq(D)}}$, is evaluated with the following equation:

$$L_{\mathrm{Aeq(D)}} = 10 \cdot \log_{10}\left[\sum_{i=1}^{16} \frac{1}{16} \cdot 10^{\frac{L_{\mathrm{Aeq},i}}{10}}\right] \qquad (3)$$

where $L_{\mathrm{Aeq},\ i}$ is the equivalent sound level of the ith interval.

Figure 13 shows a synthetic representation of the values of $L_{\mathrm{Aeq(D)}}$ referred to the four intersections investigated.

To confirm the observations made previously, it is noted that, during the daytime, the noise levels at the roundabouts are about 3–4 dB lower than the two standard intersections surveyed. If we remember that a 3–4 dB reduction is equivalent to removing half the vehicles from the road, we understand that, in the case of the experimental investigation described in this article, the roundabouts have shown a

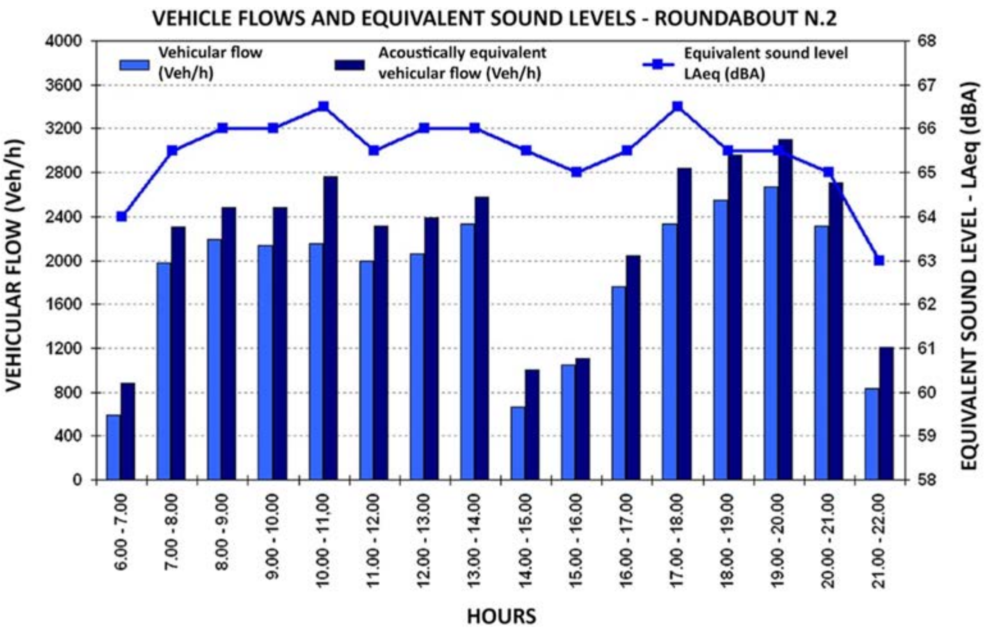

Fig. 11—Relation between vehicular flows and equivalent sound levels for roundabout N.2.

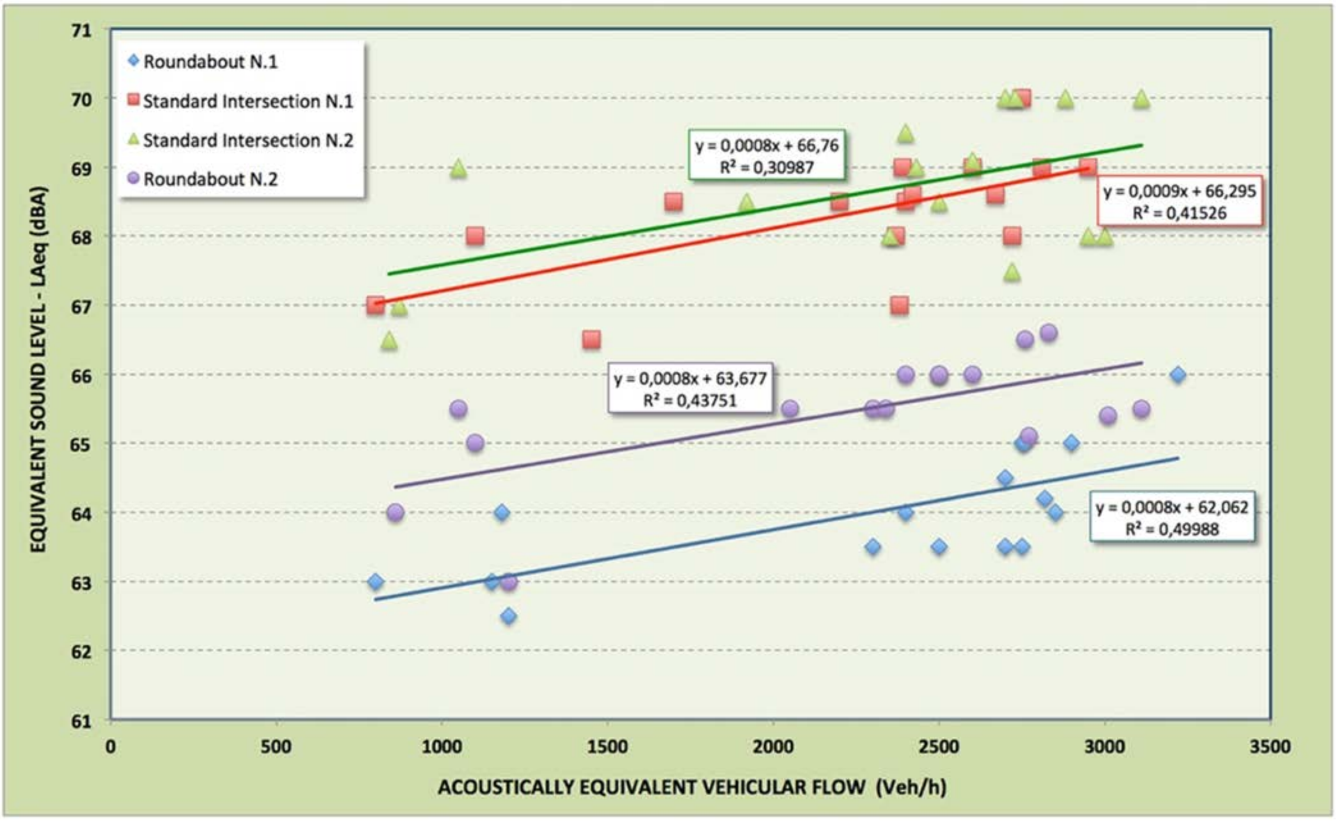

Fig. 12—Relation between acoustically vehicular flows and equivalent sound levels for the investigated intersections.

noise attenuation effect that is distinctly greater than that referable to standard at-grade intersections.

5 CONCLUSIONS

In this research, following an acoustic measurement survey conducted on a series of suburban intersections, the authors have shown that roundabouts lead to a reduction of noise compared to the standard intersections between 3 and 4 dB.

This result is consistent with the conclusions drawn by other researchers. Roundabouts, therefore, already appreciated for their safety advantages to the point of making them classify as among the most effective traffic calming

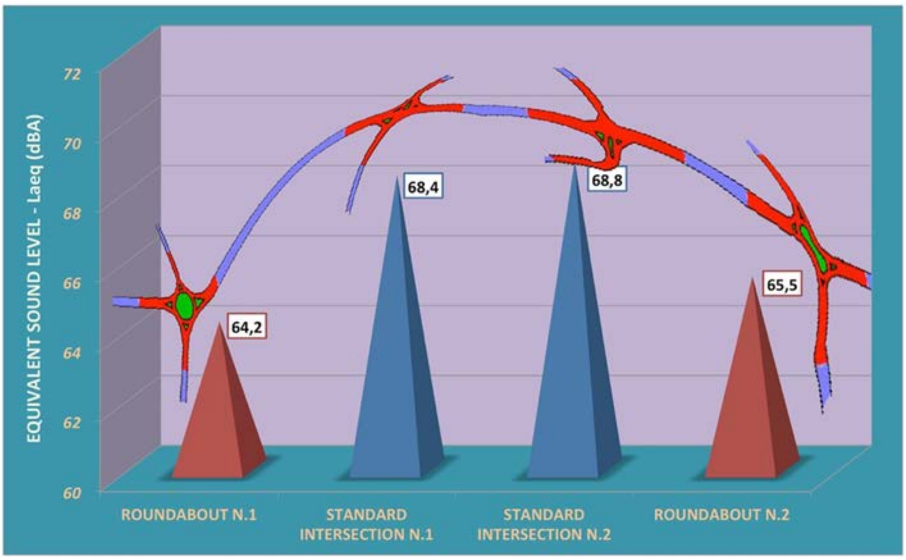

Fig. 13—Values of $L_{Aeq}(D)$ referred to the four intersections investigated.

measures, are also strategically important for noise reduction policies.

This study, therefore, is part of the research aimed at identifying those design solutions aimed at urban redevelopment from the perspective of the so-called “sustainable mobility” which includes both safety strategies for the reduction of road accidents and strategies heavily oriented to the livability of residents and to environmental quality. In this respect, the isolated design interventions, having a limited extension and consequently a low influence on the behavior of the users, are less important than the design solutions distributed sequentially in the space which instead generate a continuous influence on the users, affecting their driving behavior. It is not said, however, that certain traffic calming measures, even spatially repeated along an urban street, are able to simultaneously satisfy both the compliance with the safety criteria and the respect of environmental parameters. Speed bumps arranged in series, for example, do not guarantee the acoustic quality of the context in which they are installed, despite their remarkable effectiveness in terms of speed reduction[27]. A sequence of roundabouts, instead, will be able to ensure a significant reduction in the noise produced compared with a succession of standard at-grade intersections.

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