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STUDYING THE EFFECT OF NOISE BARRIER CHARACTERISTICS ON TRAFFIC NOISE IN URBAN AREAS

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Abstract

This research aims to identify the optimal noise concrete barrier mix through two critical stages. The initial step involves calibrating a traffic noise model via a field survey at 18 locations, encompassing volume counts and noise levels at varying distances. The subsequent step entails laboratory tests on different concrete barrier materials. The researchers developed two regression models. In the laboratory, they investigated five barrier types: reinforced, three variations of foamed concrete, and foamed concrete without aggregate. Employing a 92 dB noise source, they measured noise levels at distinct distances from the barrier. Ultimately, foamed concrete without aggregate emerged as the most effective barrier, potentially reducing noise levels by up to 46.4% at a distance of 3 meters with the use of this barrier.

Keywords:

Barrie material;
Noise level;
Traffic noise barrier;
Foamed concrete;
Ultrasonic test.

1 Introduction

Noise pollution, exacerbated by modernization and urban development, poses a significant challenge, particularly in urban areas. Noise, a pervasive nuisance, traverses various mediums such as solids, liquids, and gases, exerting a detrimental impact on human life. This impact can manifest physically, psychologically, or even mentally [2]. Noise takes on various manifestations based on factors such as intensity, source, and proximity. Common noise sources encompass street noise, industrial noise, and traffic noise. The adverse effects of noise range from nerve irritation and mental distraction to debilitating stress and hearing impairments, potentially culminating in deafness. Notably, the extent of the detrimental impact of noise varies among individuals, influenced by factors such as sound type, intensity, and the level of exposure. In addition, traffic and road noise constitute the foremost contributors to environmental noise in some countries. Traffic noise, particularly vehicular noise, emanates from engines, exhaust systems, dynamic friction, and the interaction between vehicles and the road infrastructure. It is essential to highlight that escalated traffic and an increased presence of trucks elevate the levels of traffic-related noise [9].

Various factors influence noise levels, including side distance, vegetation, topography, vehicle density, road type, road surfaces, vehicle speed, slope, truck ratio on the road, climate, and traffic barriers. Decibels, a logarithmic unit, are used to measure noise levels, expressing the ratio of sound intensity. Over the years, scientists have employed different methodologies to mitigate noise levels and traffic barriers have been one of these methodologies. Numerous researchers have extensively examined the characteristics of traffic barriers to determine the most effective ones. These characteristics encompass engineering properties and materials. This present study is grounded in both field and laboratory experiments and seeks to aid in the selection of the most appropriate noise barrier based on its material attributes. To achieve this, the researchers have developed a model that establishes a correlation between noise levels and the diverse contributing factors derived from field and laboratory findings. This study focuses on a concrete barrier, encompassing distinct characteristics.

2 Literature review

Transportation and road noise are substantial contributors to environmental noise levels in certain countries. For instance, in Egypt, road noise alone accounts for approximately 80% of the noise pollution in specific urban areas [11]. Noise sources encompass traffic noise (including cars, trains, and planes), production noise (from factories), water-related noise (related to the sounds of waves), and noise stemming from household activities. Traffic noise can be categorized into road contact noise produced by vehicle tires, vehicle noise, rail noise, aircraft noise, social noise (pertaining to pets, household activities, and car repairs), and water noise [1]. The intensity of traffic noise is influenced by various factors, including the overall number of vehicles per hour, average vehicle speed, traffic composition, and road characteristics such as width, superelevation, and gradient, as well as environmental conditions around the road like the presence of street vendors and roadside buildings, buildings' density, trees' density, and temperature [8]. Noise levels span from the sound of normal breathing at approximately 10 decibels to the deafening noise generated during the launch of a space shuttle at around 175 decibels. In addition, several factors affect auditory perception, encompassing the type of noise, the environmental context, noise concentration in a given area, and the degree to which the impact of noise varies among individuals [5].

Indeed, noise barriers showcase a diversity of types, locations, and shapes. These barriers come in different types, each characterized by aesthetic considerations, structural elements, maintenance requirements, absorptive properties, and transparency [7]. The shape of barriers can be categorized into five types: Erect type, Inverted L, Y-type, Antler type, and T-type [6]. Various materials contribute to the production of noise barriers, including concrete, wood, metal, transparent materials, and Earth berms. Among these, concrete stands as one of the most commonly used construction materials for noise protection purposes [3]. The primary objective of this research is to determine the optimal noise concrete barrier material mix through a dual-phase approach. The initial phase incorporates calibrating a traffic noise model through an extensive field survey at 18 locations, encompassing volume count and noise level measurements at varying distances. The subsequent phase entails comprehensive laboratory testing of various concrete barrier materials, incorporating ultrasonic tests. Consequently, the literature review in this research concentrates on two critical aspects. The first involves reviewing noise models and their influencing variables, while the second focuses on a comprehensive analysis of noise barrier materials as documented in the existing literature.

Multiple researchers have endeavored to develop appropriate traffic noise models that establish a relationship between noise levels and their influencing factors. Ma Xintan et al, for instance, derived three traffic noise models that delineate the correlation between noise levels and various variables, including the association between noise level and traffic volume [10]. The equation for this relationship is as follows:

$$Leq = 90.91 + .002V \quad (1)$$

Where: Leq: equivalent noise level in dB, V: traffic volume (vehicle/hour). This model demonstrates that noise levels escalate with higher average traffic speeds. The second traffic noise model delineates the relationship between noise level and average traffic speed, expressed by Equation 2.

$$Leq = 120.4 - 0.931S \quad (2)$$

Where: S: Average speed of the vehicle. This equation shows that noise level decreases with higher traffic speed. However, this conclusion seems illogical as traffic noise typically escalates with higher speeds. The relationship between noise and carriage width is shown in Equation 3:

$$Leq = 112.0 - 2.049W \tag{3}$$

Where: W: carriage width in meters. This model shows that the noise level decreases with the increased carriage width [10]. Shokouhian deduces three traffic noise models that show the relationship between noise level and various variables, including the relationship between noise level and traffic volume. The equation is as follows:

$$\mathrm{Leq} = 62.1 - 2.67\mathrm{HB} + 0.88\mathrm{HR} - 0.16\mathrm{D} + 0.0018\mathrm{TV} + 0.01\mathrm{Rs} + 0 : 092\mathrm{SP} + 2.18\mathrm{REL} \tag{4}$$

Where HB = height of the barrier (m), HR = Height of receiver (m), D = Distance from the source (m) , TV = Traffic Volume (Veh/hr), Rs = Roadway Section (m), SP = Speed (km/hr), REL = Roadway Elevation (m), Radj = Receiver Adjustment Factor (road-surface types) [12].

Noise propagation models represent another category of noise models that many researchers have explored. These models aim to estimate the noise levels at various distances from the noise source. Ma Xintan et al, deduced three forms of noise propagation, encompassing the noise prediction model, noise evaluation, and the equivalent A-weighted sound level. Equation 4 depicts the noise level at the receiver, considering the factors affecting propagation [10].

$$lp = lw + \sum \Delta \text{propagation factor} \tag{5}$$

Where: Lp: receiver noise level, Lw: The sound power level of the source, and ∆Propagation factor: The summation of the total attenuation and corrections measured due to propagation. Another noise propagation model is presented in Equation 5. This model correlates the noise level with the distance from the noise source.

$$lp = lr_0 + 101gr_0 + \sum \Delta \text{propagation factors} + 3 \tag{6}$$

Where: L_{ro} is the sound press level of the reference point and r_o is the distance from the sound source. The following model demonstrates the equivalent A-weighted sound level and the equation is as follows:

$$l_{eqi} = 10\lg \frac{Ni}{t_{vi}} + lp - 16 \tag{7}$$

Where: L_{eqi} is the equivalent A-weighted sound level of vehicle type, t_{vi} is the time measured in hours, N_i is the number of vehicles of that type, and I_p is the number of passing per hour [10].

The most popular materials for noise barriers are concrete, wood, and metals. Concrete is extensively used as a building material for both structural purposes and noise reduction. Concrete offers several advantages when considered as a noise protection material, including design flexibility, acoustic efficiency, sturdiness, weather resistance, and an extended design life. Nevertheless, there are notable disadvantages associated with using concrete as a noise-reducing material. These demerits include the concrete's high density, resulting in substantial weight, challenges in achieving an optimal design, and the difficulties researchers face in maintaining quality control [3].

The two common types of metals utilized in the construction of noise barriers are mainly mild steel and stainless steel. Mild steel is the most popular cost-effective metal in construction and it offers several advantages For instance, metal barriers are easily constructed, efficiently installed, lightweight, and serve as effective sound-absorbent material. Furthermore, metal can be fabricated using dual-leaf sheet metal systems. These benefits align with those of modular concrete or timber panels used in modular panel systems. In terms of the primary drawbacks of metal barriers, not all locations can visually benefit from specific surface finishes. Moreover, Metal barriers require sturdy fixings and the lightweight panels are susceptible to damage [3].

From the above discussion, it is evident that concrete is the most prevalent material for noise barriers, especially in a country like Egypt. Concrete not only possesses inherent advantages but also benefits from the abundance of its raw materials. Therefore, this research delves into a comprehensive study and comparison of various types of concrete to determine the most suitable one for noise barriers. This study explicitly investigates reinforced concrete, foam concrete with varying foam proportions, and foam concrete without aggregate, aiming to identify the optimal material for noise barrier construction.

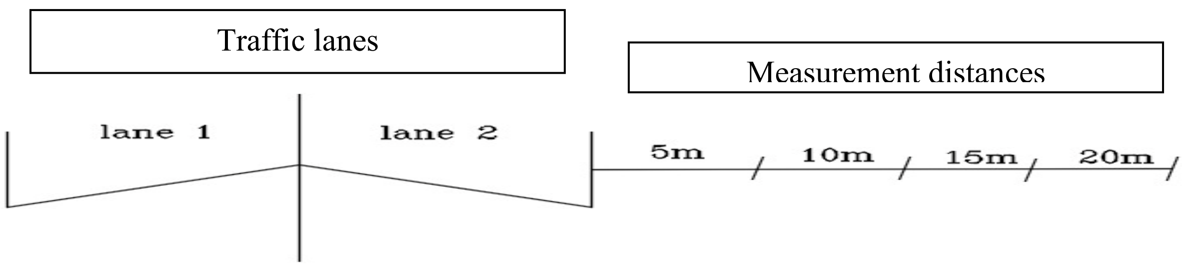

Fig.1: Noise measurement distances from the road edge in the field

3 Research Methodology

The research aims to evaluate the efficiency of noise barrier materials to ascertain the most effective barrier type. Therefore, the methodology for this research encompasses three primary steps: developing a noise estimation model derived from a field survey, determining the optimal material type for the barrier through laboratory tests, and quantifying the noise reduction achieved by the selected barrier through the application of the developed model. The model correlating the noise level with its influencing factors has been meticulously calibrated. These variables encompass distance, traffic volume, and percentage of heavy vehicles, among others. The dataset was meticulously collected from 18 diverse locations, encompassing roadway geometrical characteristics and traffic features. The data collection also involved precise measurements of noise levels at varying distances from the road edge. In the laboratory, a comprehensive study of five types of concrete barriers was conducted, including reinforced concrete and three variants of foam concrete with distinct proportions, along with concrete without coarse aggregate. Each barrier type was meticulously examined and tested repeatedly using ultrasonic tests to determine the optimal mixture. The primary measure considered was the ultrasonic speed in each sample. Based on the ultrasonic results, the researchers identified the top four barrier types. A noise source with characteristics similar to traffic noise was then applied on one side of the selected barriers, and the noise level was measured on the other side at various distances. Utilizing the estimated model derived from the field study and the identified best barrier type, the researchers compared noise levels at different distances from the road edge, both with and without the barrier. The reduction in noise level attributable to the barrier was quantified.

4 Data collection and laboratory tests

The objective of this research is to investigate the impact of barrier materials on noise levels, which entailed the collection of two distinct types of data. The first type comprised field data, aimed at measuring traffic noise and its influencing variables. The second type involved laboratory tests, specifically designed to examine the influence of barrier material types on traffic noise levels.

5 Field data

The research team utilized a sound-level device (Model: EXTECH 407735, shown in Figure 3) to measure traffic noise at 18 different locations along various roads in urban areas of Egypt. These locations, indicated in Figure 2, were strategically selected as residential areas with minimal interference from other significant noise sources.

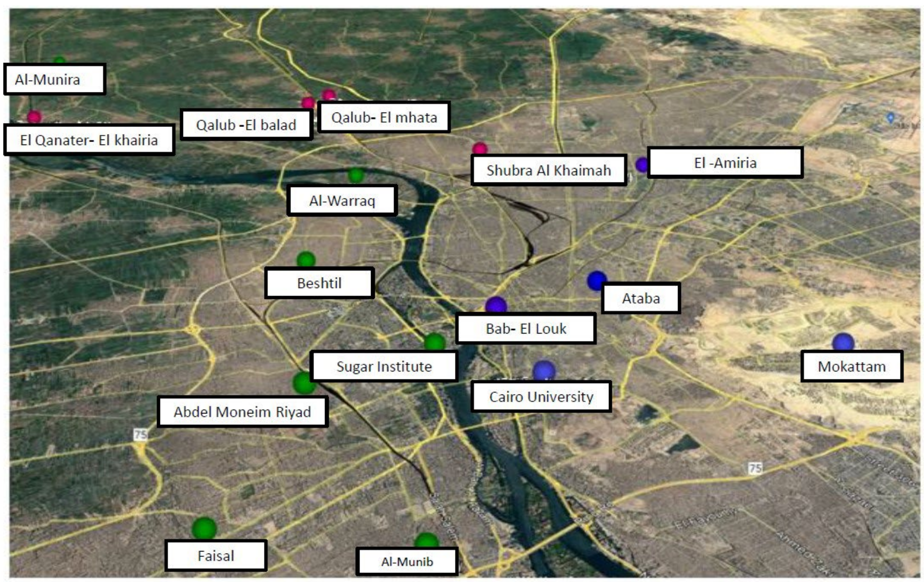

Fig.2: Measurements locations

The measurement methodology, illustrated in Figure 1, involved taking readings in three sectors within each area. Noise levels were measured at various distances from the lane's outer edge: 0, 5, 10, 15, and 20 meters. These sectors were chosen for their consistent noise levels, unaffected by acceleration effects. In addition to noise measurements, the research team also recorded traffic volume (vehicles per hour) and the percentage of heavy vehicles using video recordings. Traffic volume was measured every 5 minutes and then extrapolated to an hourly rate. A sample of the collected data is presented in Table 1

6 The study area and sampling location

Table 1 presents a sample of the collected data, illustrating the urban area location, section number, measurement distance from the street edge, average noise level at each location, traffic volume in vehicles per hour for each sector, and the corresponding percentage of heavy vehicles in the traffic volume.

Table 1: Sample of the collected data

Road Name	section	distance (m)	noise level (dB)	traffic volume (veh/hr)	%of heavy vehicle	No. of Lane	Road width
Tahrir 1	1	0	89.2	1954	6.6	2	6
		5	84.5	1954	6.6	2	6
		10	80.4	1954	6.6	2	6

		15	79	1954	6.6	2	6
		20	77	1954	6.6	2	6
Tahrir 2	2	0	91	1952	6.2	2	6
		5	88.2	1952	6.2	2	6
		10	83	1952	6.2	2	6
		15	80.3	1952	6.2	2	6
Tahrir 3	3	0	93	1963	6.3	2	6
		5	90.2	1963	6.3	2	6
		10	88.6	1963	6.3	2	6
		15	82	1963	6.3	2	6
		20	78	1963	6.3	2	6

Table 2 depicts a summary of the surveyed data, displaying the minimum and maximum noise levels across all locations, as well as the corresponding values for traffic volume and the percentage of heavy vehicles.

Table 2: Summary of the surveyed data.

Factors	**Distance (m)**			
	0	**5**	**10**	**15**
Av. Noise level (dB)	94.1	88.7	83.5	78.8
Av. Traffic volume (v/h)	1587.9	1630.8	1610.2	1592.1
Av. % of heavy vehicle (%)	7.8	7.7	8	7.4
Max. Noise level (dB)	98.2	93.4	90	87.2
Max. Traffic volume (v/h)	2325	2295	2190	2150
Max. % of heavy vehicle (%)	13.1	15.6	17.4	14.7
Min. Noise level (dB)	87	81.6	77.4	73
Min. Traffic volume (v/h)	840	865	945	850
Min. % of heavy vehicle (%)	2.6	1.96	3.22	2.42

Fig.3: Noise level meter Model EXTECH 407735 (SLM)

Fig.4: The used frame for the test

Fig.5: The ultrasonic test system

Fig.6: Concrete cube

7 Laboratory experimental tests

The characteristics of noise barrier materials were assessed in terms of their efficacy in reducing traffic noise. This study delved into the impact of various materials, including reinforced concrete barriers, foam concrete with different foam proportions, and foam concrete without aggregate. The research team conducted multiple trials for each barrier type to identify the most effective barrier in terms of noise reduction. Each trial involved mixing materials in different proportions and casting them into cubes measuring 15x15x15 cm. Subsequently, an Ultrasonic test was employed to assess each trial, aiming to determine the mixture with the lowest ultrasonic speed. The Ultrasonic pulse velocity apparatus, known for its flexibility and widespread use in concrete testing, was chosen as a void and crack detection technique. The apparatus includes a PUNDIT, ultrasonic wave transmitter, receiver transducers, and a calibration block. In this study, pulse velocity was measured through 15 cm concrete cubes. Figures 4, 5, and 6 reveal the ultrasonic test apparatus. This test aims to ascertain the speed of waves in each concrete cube, enabling the measurement of their noise reduction capabilities. Table 3 displays the ultimate chosen mixture design based on the most promising results obtained from the ultrasonic tests.

Based on the results from the ultrasonic tests, five models of these mixtures were constructed with dimensions of 1.5 x 1.5 x 0.07 m. A noise source emitting 92 decibels (the average noise level from the field survey) was placed at a distance of 2 meters from the face of the barrier. Noise measurements were taken at distances of 0, 1, 2, and 3 meters from the barrier's back. Figure 9 provides a visual representation of the sample barrier utilized in the study.

Table 3: Mixture design

Type	Cement [Kg/m^3]	Water [Kg/m^3]	Foam [mL/m^3]	Coarse Aggregate [Kg/m^3]	Sand [Kg/m^3]	Sp [Kg/m^3]	Steel [Kg]
Reinforced concrete	400	200		0.8 m3	0.4 m3	—	120
Foamed concrete without aggregate	740	200	1085	—	940	5.2	—
Foamed concrete (1)	350	190	501	1028	591	—	—
Foamed concrete (2)	413	190	1003	1117	698	—	—
Foamed concrete (3)	412	209	1500	1092	667	—	—

Sp: Additives to improve the workability of concrete

Fig. 7: Used foam in the mixture

Fig. 8: Concrete Mixture

Fig.9: Noise barrier

Figure 10 illustrates the testing method employed to evaluate the effectiveness of various barriers, as indicated in Table 3, in reducing noise. The figure clearly shows that the noise source is positioned at a distance of 2 m from the barrier, and noise measurements are taken at distances of 0, 1, 2, and 3 m on the other side.

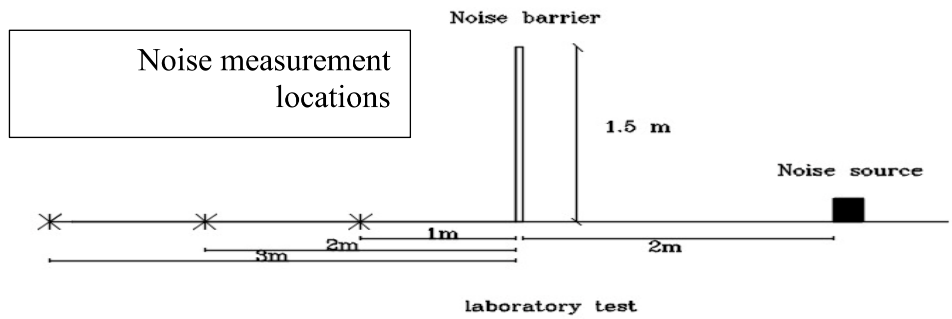

Fig.10: laboratory test measurement for noise barrier

Table 4 presents the laboratory test results for testing noise barriers. The table shows the noise level at distances 0, 1, 2, and 3 m, the strength of the concrete mix, and the ultrasonic wave velocity for each barrier type. It is clear from the table that the best concrete type in terms of ultrasonic velocity is foam concrete (3), while the best one in terms of noise reduction is the concrete mix without coarse aggregate.

Table 4: Laboratory test results on barriers

Type	Distance	Noise level	Strength [kg/cm^2]	Velocity [m/s]
Reinforced concrete	0	92	____	____
	1	69.2		
	2	65.3		
	3	60.9		
Concrete without coarse aggregate	0	92	30	2.6
	1	60.8		
	2	54.5		
	3	48.7		
Foam concrete (1)	0	92	90.9	4.3
	1	68.3		
	2	65.7		
	3	61.1		
Foam concrete (2)	0	92	79.32	2.2
	1	67.8		
	2	65.1		
	3	60.5		
Foam concrete (3)	0	92	22.69	0.6
	1	65.7		
	2	62.5		
	3	59.9		

8 Data Analysis

The initial aim of this analysis is to calibrate a regression model correlating noise levels with their influencing variables for subsequent utilization in barrier testing. The influencing variables encompass the distance from the noise source, traffic volume, and the percentage of heavy vehicles.

Determine the optimal noise barrier material. Figure 11 sheds light on the correlation between traffic volume and noise levels at various distances from the noise source. It is evident from the figure that as traffic volume increases, noise levels also escalate. Furthermore, greater distances from the noise source correspond to lower noise levels.

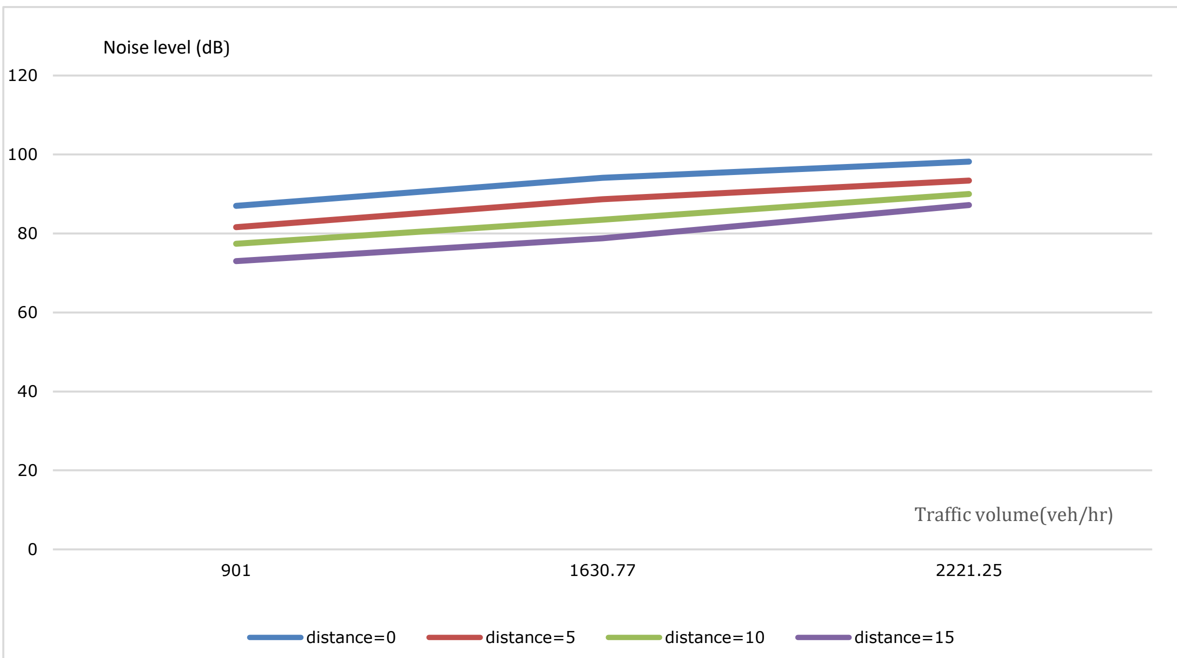

Fig. 11: Shows the relationship between noise level and traffic volume at all distances.

The second objective entails analyzing the laboratory data output to numerous trials were conducted to determine the optimal combination of independent variables for creating the most accurate regression model for estimating noise levels. Equation 8 delineates the optimal relationship among noise level, distance, and traffic volume. The model underscores an inverse correlation between noise level and distance, and a direct correlation with traffic volume. Table 6 provides a comprehensive summary of the regression statistics

$$\text{Noise level} = 91.78 - 1.001\,\text{distance} + 0.001268\,\text{traffic volume} \quad (8)$$

Table 6: summary of regression statistics

R Square	0.831621
Adjusted R Square	0.830856
Significance F	4.59E-87

Considering the permissible noise level in accordance with the Environmental Affairs Agency's recommendations for Greater Cairo, specifically for residential areas situated on roads less than 12 meters wide with diverse commercial and recreational activities, maintaining the noise level at or below 65 decibels is crucial, (as per https://www.eeaa.gov.eg/) . Consequently, utilizing the derived noise model, an estimate for the safe distance from the road edge for constructing residential buildings has been derived and is presented in Table 7 and Figure 12.

Table 7: Safe distance from the road edge for residential buildings

Noise level [db]	Traffic volume [veh/hr] for two direction	Distance [m]
65	500	27.38
65	1000	28.019
65	1500	28.65
65	2000	29.28
65	2500	29.92
65	3000	30.55
65	3500	31.18
65	4000	31.82

The estimated distance mentioned above is suitable for direct noise exposure. However, various factors inside buildings, such as wall thickness, window type, and other architectural features, can influence the noise level inside the building

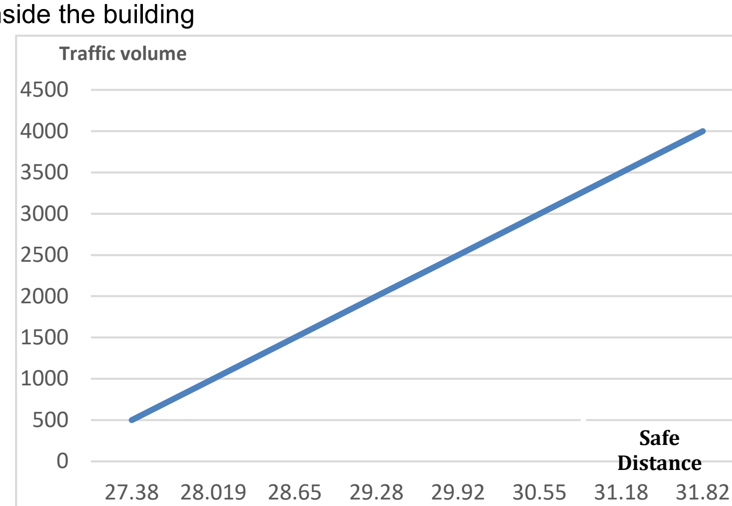

Fig.12: the relation between traffic volume and safe distance for residential buildings

It is evident from Figure 12 that with an increase in traffic volume, the necessary safe distance for constructing a residential building also escalates.

Table 8: a comparison of noise levels with and without barrier

Distance	Noise level without a barrier [db]	Noise level with a barrier (concrete without aggregate) [db]	Percentage of reduction
1	92.83	60.8	34.5
2	91.8	54.5	40.6
3	90.8	48.7	46.4

9 Conclusion and recommendation

The primary objective of this research is to assess various types of concrete materials to determine the most suitable materials for traffic noise reduction barriers. Different concrete mixtures were meticulously prepared and subjected to preliminary investigation through ultrasonic tests. From these tests, the top four performing mixtures were selected and further evaluated for their noise reduction capabilities. Models for noise barriers, each with dimensions of 1.5 x 1.5 x 0.07 m, were fabricated in the laboratory.

A noise source was positioned on one side of each model, and noise levels were recorded on the other side at varying distances from the noise barrier. To gauge the efficacy of these barriers in noise reduction, a model was formulated correlating noise levels at different distances from the road edge with the influencing variables, utilizing data obtained from an extensive field survey conducted across 18 locations on Egyptian roads. The established model was then employed to estimate noise levels at the same distances utilized in the laboratory. A comparative analysis of results was conducted for scenarios 'with' and 'without' barriers. The findings demonstrated that foamed concrete without aggregate was the most effective material in reducing noise. Based on these findings, the authors draw the following conclusions:

1) The optimal barrier for noise reduction is constructed using foamed concrete without aggregate. Therefore, the researches of this paper strongly recommends its implementation for noise reduction in urban areas.

2) These results were compared with the noise levels at equivalent distances in the case of using concrete barriers without aggregate. The comparison clearly indicates that the noise level reduction with these types of barriers can be as substantial as 46.4% at a distance of 3 units. This signifies the highly effective nature of this particular barrier type.

3) The estimated safe distance should exceed 31.82 meters when the traffic volume exceeds 4000 vehicles per hour. Utilizing the estimated model in Equation 7, we have computed the noise levels at distances 1, 2, and 3 in the absence of barriers, presented in Table 8.

4) The noise level is influenced by several factors, including the distance from the noise source, traffic volume, and the percentage of heavy vehicles. However, the heavy vehicle factor was excluded from the model due to its correlation with traffic volume.

5) The optimal noise models comprise a linear regression model based on distance alone or incorporating both distance and traffic volume. Both of these models exhibited satisfactory statistical outcomes.

6) Upon comparing noise barriers constructed from reinforced concrete, foamed concrete without aggregate, and foamed concrete with varying foam proportions, it was determined that foamed concrete without aggregate proved to be the most effective in noise reduction. The optimal mix composition for this type, based on ultrasonic test results, includes 470 kg of cement, 200 kg of water, 1086 ml of foam, 940 kg of sand, and 52 kg of SP per cubic meter

7) When implementing the suggested noise barrier, a notable reduction in noise levels exceeding 46% can be achieved.

8) From ultrasonic tests, it can be deduced that as a material's capability to lower ultrasonic speed increases, its potential to reduce noise levels also amplifies.

In addition, it can be recommended that:

1) In areas with elevated noise levels, diminishing the percentage of heavy vehicles is vital to mitigate the adverse effects of noise.

2) The estimated noise models should be incorporated into traffic and economic studies to assess the prospective impact of transportation projects on society.

3) The optimal noise barrier material is foamed concrete without aggregate. Hence, it is highly recommended for noise reduction in urban areas.

4) In future endeavors, researchers are encouraged to invest significant efforts in studying the impact of geometric characteristics of barriers on noise reduction, aiming to determine the most effective noise barrier dimensions.

5) In future research, it is vital to invest significant efforts in exploring the influence of geometric characteristics of barriers on noise reduction, aiming to determine the optimal noise barrier dimensions for enhanced effectiveness.

6) The necessary safe distance for constructing a residential building should exceed 31.82 m, particularly when the traffic volume surpasses 4000 vehicles per hour.

7) In future studies, the research team recommends investigating the impact of landscaping and other noise reduction treatments.

Declarations

1) Authors declared that there are no available fund source and authors has done the research on their own cost

2) Authors also declared that the data used in this research will be available upon request

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