Istraživanja i projektovanja za privredu
ISSN 1451-4117
DOI:10.5937/jaes0-42087
www.engineeringscience.rs

Journal of Applied Engineering Science
Vol. 21, No. 3, 2023
Short Report
Paper number: 21(2023)3, 1120, 785-794

USE OF SOUND ATTENUATION WITH SONIC CRYSTAL STRUCTURES IN RESIDENTIAL AREAS DUE TO HIGHWAYS

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Indonesia is a growing nation that needs assistance placing structures beside roadways. Ideally, one should place buildings along residential roads rather than main or collector highways. Due to the high levels of vehicular noise pollution on Indonesian arterial and collector roads, many buildings are located alongside them. This negatively impacts both the environment and human health. As a result, efforts must be made to reduce noise, and one such endeavor is the construction of noise-absorbing structures. Walls are commonplace, noise-absorbing structures with low sound-absorption capacities and fewer aesthetic drawbacks. Sonic crystals are a novel method of noise reduction. This study aims to evaluate the effectiveness of sonic crystals and their possible application in residential areas to reduce noise from the roads. Tests were carried out in an outdoor setting using a real scale. By describing the sonic crystal, it is possible to determine quantitatively how much sound it can absorb. It is also possible to obtain the sound's shapes that sonic crystals can attenuate. The findings indicate that the maximum IL value is 21.57 dB, and the average IL value is 16.90 dB. The area that the sonic crystal attenuates enough is about 3 meters after the crystal and roughly 2 meters from the crystal's center axis, respectively. These findings concern using sonic crystals to lessen noise from traffic in residential areas.

Keywords: transport, insertion loss, sonic crystals, attenuation

1 INTRODUCTION

Designing structures along highways is a challenge in Indonesia, a developing nation. Buildings are conveniently situated at the sides of residential streets. Due to the high vehicle intensity of arterial and collector roadways, structures shouldn't be located right next to the road. Buildings along arterial and collector highways consequently have environmental issues, including noise from traffic. Unwanted sound, or noise, harms the environment [1]. According to [2], noise is the unwelcome sound of an activity or enterprise over time. Noise harms health and disturbs the comfort of the surroundings. Transportation noise causes concerns to both physical and emotional health [3]. The detrimental effects of noise on human health have been the subject of numerous research. [4] Claimed that late-night traffic noise disrupts and shortens sleep, raises stress hormone levels, and intensifies oxidative stress on the brain and blood vessels. These elements can increase blood pressure, inflammation, and vascular dysfunction, raising cardiovascular disease risk. According to the WHO, traffic noise may raise the risk of coronary heart disease. Noise can have an impact on psychological consequences in addition to health effects. [5] Discovered that noise can impact a person's sense of anxiousness.

Noise is produced when a noise source is present. A noise source is a sound source whose presence is thought to impair hearing from fixed and mobile sources [6]. A mobile source is an emission source from motorized vehicles that move or are not set in one spot. Stationary sources, in contrast, are emission sources that are fixed in a location [7]. Nearly every country has attempted to study the utility of noise. For instance, [8] looked into noise and air pollution in Belgium. As a result, noise levels on routes with plenty of traffic can get up to >80 dB. The study by [8] can be used to compare countries with many automobiles. In Surakarta City, Indonesia, where this research was carried out, there are various classifications of roadways. Ir. Juanda Road in Surakarta City is a class II route with a secondary arterial road function, and [9] has investigated how noise happens on this road. The findings show that the measurement distance has an impact on road noise. The survey standard used is regulations from the Directorate General of Highways, Directorate of City Road Development concerning Survey Guidelines and Calculation of Traffic Travel Time, No. 001/T/BNKT/1990. The Sound Level Meter is installed with the help of a tripod with a height of 1.2 meters above ground level, with the microphone facing the main road and placed at a distance of 0, 5, 10, and 15 meters from the roadside. Most of the value, 90 dB, occurs at a measuring distance of 0 meters from the road, and the significance decreases with increasing measurement distance. The noise level is typically 75–80 dB. Since this result falls below the cutoff set by [2], it is imperative to lessen transportation-related noise.

The noise isolation approach and the noise absorption method are two ways to lessen noise, according to [10]. The noise isolation technique blocks and interferes with sound propagation to minimize noise. The noise absorption method attenuates and attenuates sound energy while simultaneously reducing noise. The reflecting noise barrier is the noise isolation technique that is most frequently utilized. However, reflective noise barriers are made to reflect most traffic noise, which might be an issue when it's necessary to minimize sound reflections to noise-sensitive locations near roadways.

Specifically dense mixtures are great sound reflectors. Different types of concrete perform differently as sound conductors. It was discovered that the type of aggregate, pore size, and distribution, as well as modifications in the design of the concrete mixture, all significantly impact the degree of sound reflection in modified concrete [11]. Buildings designed to decrease and reduce noise from motorized traffic include buildings with walls or walls with a particular shape and specific materials [12]. Using concrete walls or other noise-absorbing structures to minimize noise is very successful. However, it still causes issues like air circulation obstructed by the wall and sound reflections that travel from one side of the wall to the other [13].

Sonic crystals are a breakthrough in noise reduction that addresses the issue above. According to [14], distributions are arranged in periodic configurations using square, rectangular, or triangular patterns to create non-homogeneous formations known as sonic crystals. According to [15], systematic structure placement is preferable to panel-based sound barriers. Real-scale, modeling, or numerical techniques have all been used in several sonic crystals research. Although real-scale study [16] has been completed, it has not yet been applied in the field and is still being tested in the lab. The PVC is spaced 20 cm apart and has a diameter of 6 inches. It is 3 meters high. - Using the Astley-Leis in finite element method (IFEM) modeling, the highest IL is 22 dB at a frequency of 2 kHz [17]. A lab experiment employing cylindrical steel material and a non-real scale discovered that the highest IL of 15 dB happened at a frequency of 2 kHz. At some frequency, the results of numerical calculating with non-real scale calculating diverge quite a bit [18]. The use of sonic crystals has enabled noise from the room heater to be reduced and the sound level to be lowered by 10 dB [19]. To the author's knowledge, there isn't currently a sonic crystal that can be used directly on highways to lessen traffic noise.

The characterization of sonic crystals has been the subject of numerous studies. According to [16], research done under EN 1793 criteria in a lab produces results nearly identical to those of studies done under field conditions. However, an assessment considering the current circumstances has never been carried out. As a result, the evaluation of sonic crystals used as a sound barrier in residential areas is the primary goal of this study. Research demonstrates that vehicle noise and sonic crystals are dealt with individually. As a result, this research is anticipated to link sonic crystal research with future deployment because of traffic noise.

The amount of sound attenuation that can be achieved using a sonic crystal made of PVC tube material will be examined. The contour of the sound intensity distribution must first be analyzed to determine how much area can be lowered. Then, a rough illustration of its use in the residential transportation sector will be provided. This work aims to quantify the Insertion Loss (IL) of sonic crystals in open areas. The second objective is to determine the potential of using sonic crystals in residential areas next to highways. Thus, it is possible to implement sonic crystals for use on roadways in residential areas, which can solve concerns with traditional noise absorbers, such as sound reflection, visual problems, and disrupted air circulation.

2 THEORY

Sonic crystals are irregular, non-homogeneous structures with square, rectangular, or triangular patterns. Three types of sonic crystals exist one-, two-, and three-dimensional. The periodic arrangement of a steel sheet is similar to a one-dimensional sonic crystal. For instance, two-dimensional sonic crystals resemble cylinders spaced uniformly. For example, spheres are stacked in a cubic space in three-dimensional sonic crystals [20]. However, two-dimensional sonic crystals are the simplest to use in real life [21].

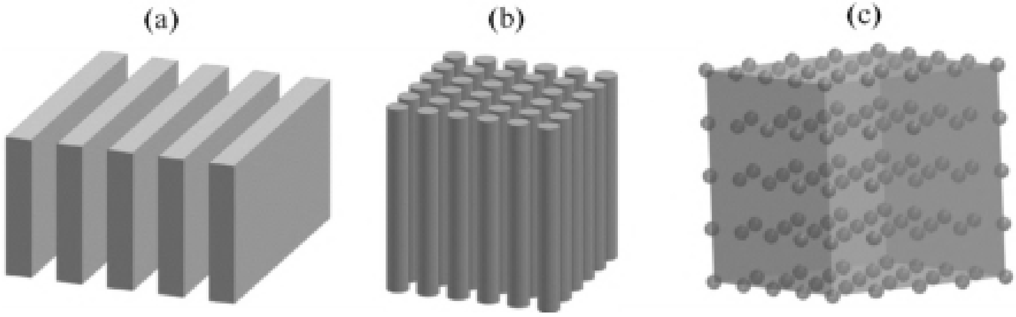

Fig. 1. Types of sonic crystals (a) one-dimensional (b) two-dimensional (c) three-dimensional. [14]

Sonic crystals are based on the periodic configuration of the lattice. With this setup, the sound can be hushed inside the band gap, which is a range of frequencies. This sound suppression is accomplished through destructive interference of the sound wave generated by scattering in the band gap and the evanescent effect [22]. As a result, when a sound wave passes through a periodic structure, its spectral properties change, and the incident wave frequency is significantly lowered [23].

Sonic crystals, which function as piezoelectric transducers, can be utilized to reduce noise [40]. Sonic crystals can transform mechanical energy from acoustic vibrations (noise) into electrical energy when applied to materials subjected to these vibrations. The electrical energy can then be converted back into mechanical vibrations with the opposite phase and amplitude, essentially "canceling" or "dampening" the current noise.

Sound suppression with sonic crystals is often based on Insertion Loss (IL). By experimenting with the spatial configuration (sonic crystal lattice) or filling factor of the sonic crystal, insertion loss optimization is carried out [24–26]. The number of sonic crystal rows influences IL. [27] Discovered that numerous three sonic crystal rows work best with a cylindrical cross-sectional form and a square or triangular lattice. When the calculation was changed to be 10% or 20% more significant for the sonic crystal's size, [28] saw that the IL was barely impacted by less than 0.5 dB. The sonic crystal should be positioned parallel to the source, mainly if the source is linear as a railroad or highway [29].

3 METHOD

The material construction for the sonic crystal sample is a PVC tube with a diameter of 6 inches and a height of 4 meters. An arctic-material cover is used to seal the tube on both sides. The spacing between sound crystals is 20 cm from one sonic crystal center to another, and the sonic crystal lattice is 3 m wide. According to [16]'s research, the gap between sonic crystals is set. This study's sonic crystal structure is square. Three rows are chosen because research shows that this number of sonic crystals is the best, according to [27].

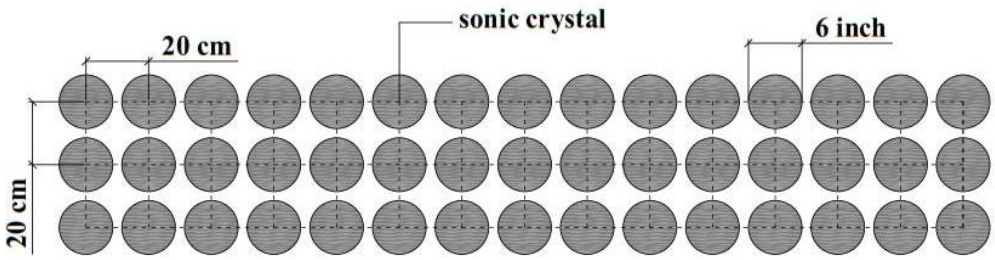

Fig. 2. Square Lattice of Sonic Crystals

The height of the sonic crystal is 4 m above the field's base. According to [30], motorized vehicles' sizes range from 1.3 to 4.1 meters. So the motorized vehicle causing the noise can be found at a height of less than 4 meters. In contrast, the receiver's location—particularly buildings and people—is below the sonic crystal's height. Meanwhile, the average size of an Indonesian is 158.17 cm, according to NCD Risk Factor Collaboration data. As a result, the data is also adjusted to 1.5 meters according to the receiver's microphone height. The receiver's microphone's height and the sound source's height of 1.5 meters match the study conducted by [16].

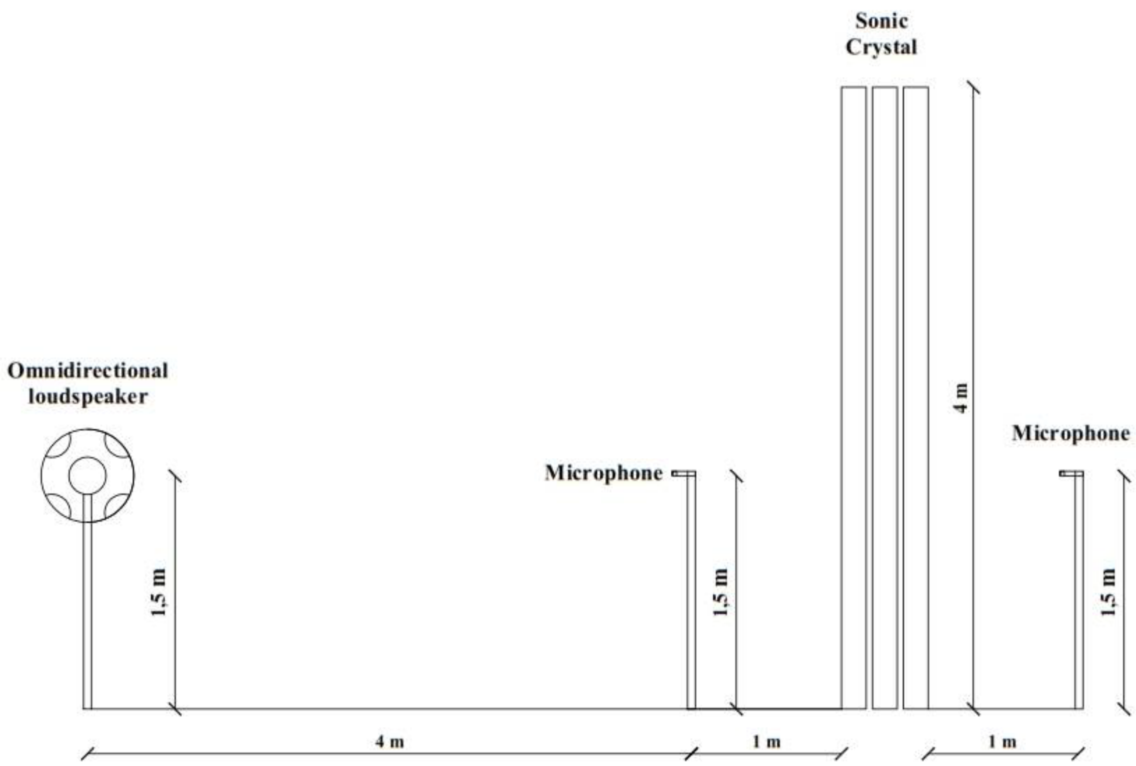

Fig. 3. Position and height of the sonic crystal and microphone

A meter separates the sound receiver from the sonic crystal, which is situated in front of and behind the receiver. A loudspeaker is positioned 5 meters before the sonic crystal as the noise source. Before being exposed to the sonic crystal, the receiver in front of it seeks to gauge the volume of the sound. The sound that travels through the sonic crystal is picked up by the receiver in the back. There are 72 locations on the receiver behind the sonic crystal. Figure 4 depicts the arrangement of the sonic crystal testing points. The sonic crystal's nodes are colored red for those in front of it and green for those in the back. The point before the sonic crystal is designated with the letter S to make point naming easier (Source). Row (R), from rows one to eight, is coded simultaneously as the sonic crystal. The first through ninth columns are all coded with the letter C. The area after the sonic crystal is 64 m2 because there are 1 m grid points between each point.

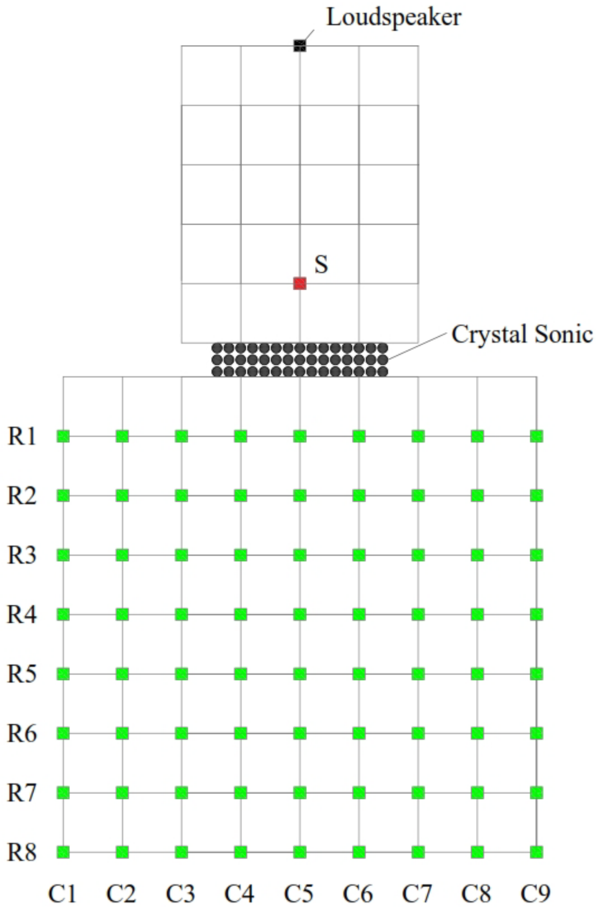

Fig. 4. Point Configuration of Sonic Crystal Testing

The Sound Level Meter Types 2270 from Brüel & Kjaer is being used as the test instrument for the direct calculating method. The instrument's omnidirectional loudspeaker serves as the sound source. It was utilizing a Type 4190 12-Inch Free-Field Microphone to record sound. Power amplifiers that employ Power Amplifier Types 2734 are supporting devices for audio sources. Setting tools and testing in open space is shown in the image below.

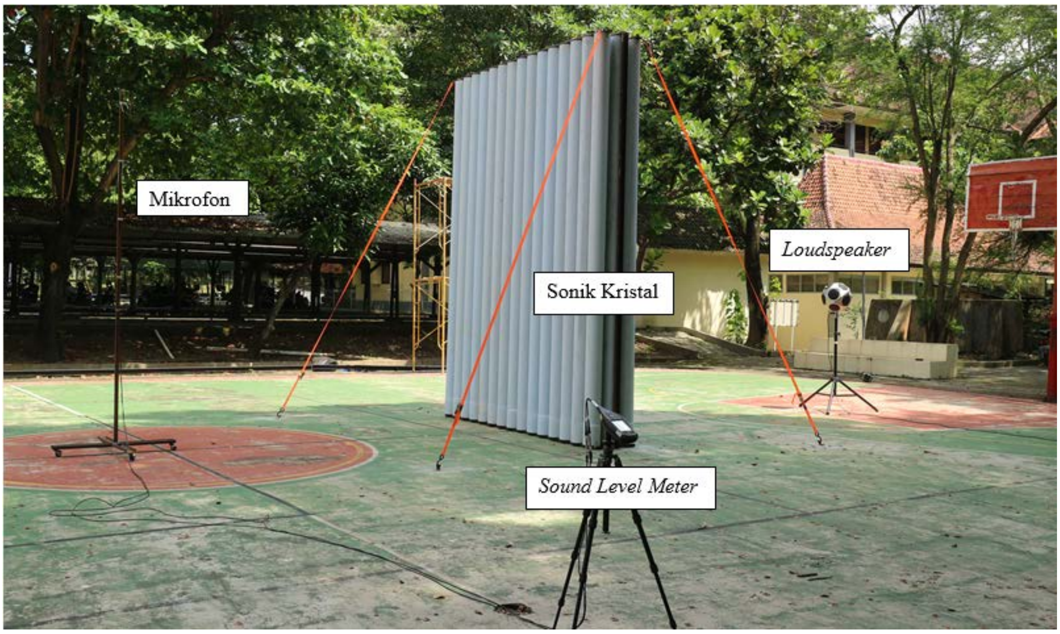

Fig. 5. Setting tools and testing in open space

Each test site had a sound level calculated. At each point, calculations are taken with no more than a 20-second gap between sizes. This was done to ensure that outside factors like wind, weather, and temperature didn't significantly impact the outcomes at each point. The research was conducted when the weather was sunny, with temperatures ranging from 30 to 32 degrees Celsius. The research was stopped when the weather was cloudy or drizzling. Air humidity ranges, on average, 81%. According to NEN-EN 1793-6+A1, a sound reflection that occurs can be avoided by placing the test location as far from potential objects as reflecting sound. There is no exact provision for how much distance must be met so that the sound is not mirrored. But for reports, it's a good idea also to report field conditions. This investigation uses a frequency of 1000 Hz. This frequency is consistent with [20], which states that the frequency of traffic noise ranges from 100 Hz to 5 kHz with a peak of 1 kHz, as well as with research by [31]. Several studies have stated that transportation noise is at a low frequency but has a high sound decibel. As a result, 1 kHz will be used as the contouring frequency. Calculating how many sonic crystals can achieve sound absorption is the technique used to analyze the results of sonic crystal testing. This analysis is carried out by logging the intensity level readings obtained from tests conducted before and after the installation of sonic crystals using a sound level meter. Using the Surfer application, a contour map of the frequency's sound distribution is created. We entered each test point's coordinates into the surfer application. We first entered the test point coordinates, and then we entered the sound value at each coordinate location. These points provide us with the sound contour output from the surfer application. So it's essential to understand the sound dispersion contour map and the amount of sound absorption.

4 RESULT AND DISCUSSION

4.1 Insertion Loss of Sonic Crystal

The test results revealed the sound pressure level at each site (SPL). Based on this value, the Insertion Loss derived from each point is computed. The average sound pressure level after the sonic crystal is 64.70 dB compared to before the sonic crystal is 81.6 dB. As a result, the maximum insertion loss value, insertion loss, and average sound level for each row vary. Figure 6 below displays each sonic crystal row's average sound magnitude, average IL, and maximum IL values.

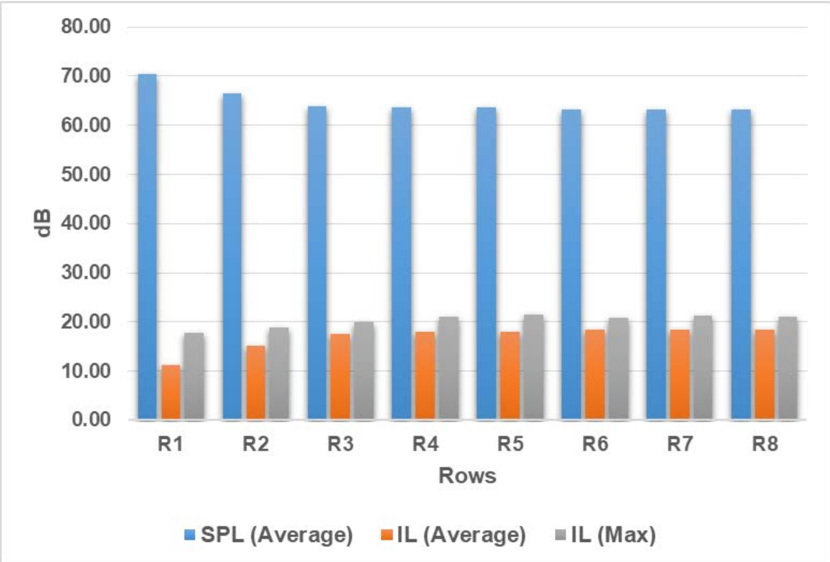

Fig. 6. Average Sound Pressure Level, Average IL, and Maximum IL of Each Sonic Crystal Row

Figure 6 shows that rows 1 through 8 exhibit lower average sound pressure levels, primarily because sound diminishes more rapidly as objects move farther from the sonic crystal. The IL value then tends to rise for rows 1 through 8. This result is consistent with previous research [38], which shows that the sound decreases as the receiver moves away from the sonic crystal. The average IL values in the first, second, and third rows are 11.19 dB, 15.11 dB, and 17.68 dB, respectively. The average volume is between 17 and 18 dB from the third to the eighth row. The first, second, third, and eighth rows are significantly different. The seventh row's average IL value is 18.44 dB, the highest. At the same time, the most significant IL value in the fifth row is 21.57 dB. The average sound size, insertion loss, and maximum values for each column also differ. Each sonic crystal column's intermediate sound pressure level, average IL, and maximum IL values are shown in Figure 7 below.

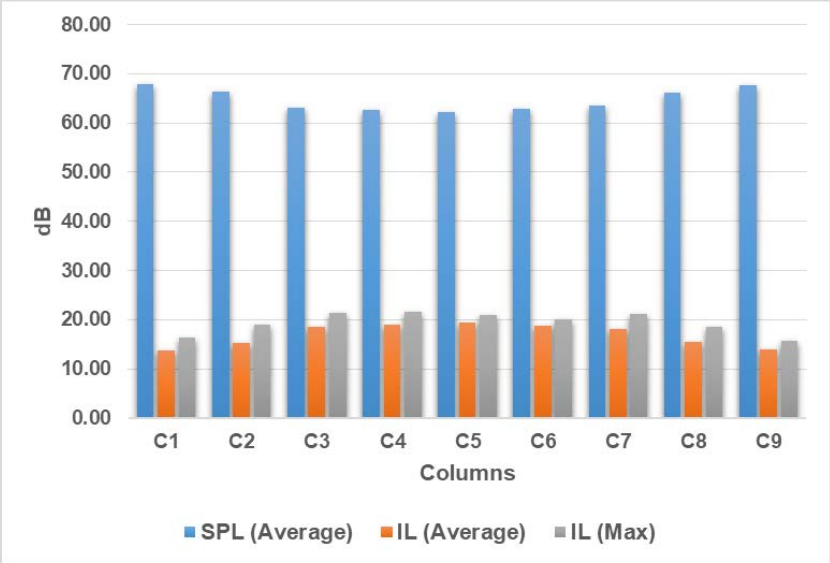

Fig. 7. Average Sound Pressure Level, Average IL, and Maximum IL of Each Sonic Crystal Column

The first and ninth columns in Figure 7 have the most significant average sound size, which subsequently declines until the fifth column. This is because column 5 is the central column, the center of the sonic crystal and the loudspeaker. The average IL values in the first, second, and third columns are 13.73 dB, 15.35 dB, and 18.48 dB. The third, fourth, and fifth columns are 18.48 dB, 18.98 dB, and 19.36 dB. The third, fourth, and fifth columns in Insertion Loss differ significantly from the first and second columns. The average IL values in the ninth and eighth columns differ from the seventh, sixth, and fifth columns. The highest IL is found in the fifth column, which is on the center axis and includes the loudspeaker and sonic crystal center. Moving away from the central axis causes IL to decrease, with the most significant decrease occurring at a distance of 4 meters. The average IL value in the fifth column, 19.36 dB, and the maximum IL value in the fourth column, 21.57 dB, is the most significant.

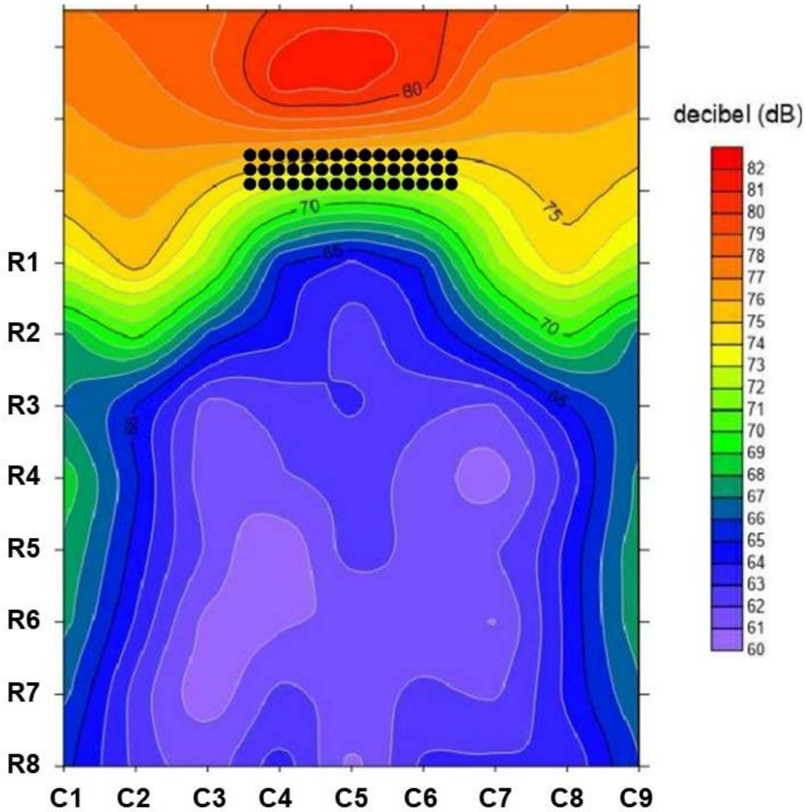

Fig. 8. Sound Contours of Sonic Crystal Testing

Additionally, the surfer application was used to process the sound pressure level at each point, and the result was a set of sound shapes. The sound result that has been rendered as sound contours is shown in Figure 8. At the moment after the sonic crystal, the sound contour displays the sound difference in each row and column. The sound has greatly diminished starting in the third row compared to rows 1 and 2, like the analytical results from Figures 5 and 6. The blue tint predominating in the three rows up front serves as a hint. At the same time, there are still many sounds in rows 1 and 2, particularly in columns 1, 2, and 9, 8, displayed in red, orange, yellow, and green. The red color represents a sound pressure level of 82 dB, while the green ranges from 67 dB to 73 dB. The final blue color represents 63 to 73 dB, while purple represents the lowest value, 60-63 dB. The red to purple colors represent the largest to smallest IL values. The distance from the sonic crystal, as well as the length of the sonic crystal, affect the area where sound attenuation has the most significant impact. The lowest sound level or highest IL is displayed in the fifth and fourth rows, where the sound contour is shown in purple. This outcome aligns with the information presented in Figures 6 and 7.

4.2 Potential Implementation of Sonic Crystals for Indonesian Noise Attenuation

The way to reduce noise in Indonesia has been codified in [6], and it involves employing Noise Barrier Walls. ALWA material is used for the required noise barrier walls. ALWA (Artificial Light Weight Aggregate) is a type of artificial aggregate produced at high temperatures and lighter than regular aggregate or other artificial aggregates. ALWA can be a byproduct of the iron mill due to the blast furnace process. Composition = 1:4:4 (Cement:Sand: ALWA) [39].

In Indonesia, researchers have conducted numerous studies on noise reduction. One such study [32] focused on examining the efficiency of noise absorption caused by transportation in a school located in Cibinong. The material employed is reinforced concrete, measuring 20 meters in length and 3 meters in height, made of 3 cm thick concrete slabs. This wall has a noise reduction range of 6.9 dB to 27.9 dB. Due to dif-fraction, this barrier is ineffective against low-frequency sound but can be treated at the edge of the barrier to increase the absorption of traffic noise.

[33] Investigated the impact of local knowledge structures on soundproofing in Bali. Every home in Bali has a local identity-defining traditional wall. There are three types of barriers, each made of concrete, brick, and natural stone. These walls are 12 cm thick and 175 cm high, virtually to the millimeter. The noise attenuation produced by natural stone and brick walls is 11.93 ± 2.77 dBA and 11.71 ± 3.11 dBA, respectively, whereas concrete blocks offer the most significant noise attenuation (16.99 ± 5.48 dBA).

Building stiff barriers or plants has been used to lower noise levels. To lessen the noise from road traffic, (34) obtained alternate sorts of ornamental plants. A six-meter sound tunnel is an instrument in use. In front of the sound source, decorative plants are at the tunnel's entrance. A sound level meter calculates the noise level at a distance of zero meters and every additional meter. Imodia had the highest noise-reduction efficiency (16%), followed by Furing Telor, Soka, Furing Tissue, Walisongo, and Pucuk Merah. The size of the leaf surface area varies from the smallest to the widest in each of these plant varieties.

However, traditional noise barriers have a lot of issues. Conventional noise barriers, for instance, can reflect sound energy over the road to the receiver on the other side if not treated for absorption [35]. The structure's bulk obstructs vision, preventing light from entering. [36]. Plant noise barriers require additional attention [37]. The author points out that researchers have conducted very little research on using sound barriers in residential areas in Indonesia. As a result, this study could develop a sound barrier with a sonic crystal structure for use in residential areas. Researchers utilize a PVC pipe as the sonic crystal. The crystal's sonic lattice allows light to penetrate through the gaps, which helps overcome the limitation of traditional barriers that block light from entering.

The research findings indicate that different sites with sonic crystals show varying degrees of sound attenuation. After the process, the average sound pressure level reaches 64.70 dB, and the average Insertion Loss is 16.90 dB. Consequently, some sounds exceed 64.70 dB, while others are lower after passing through the sonic crystal. Assume that the goal is to achieve an average sound pressure level. Figure 9 illustrates the outcome of restricting the area with a sound magnitude value below 64.70 dB.

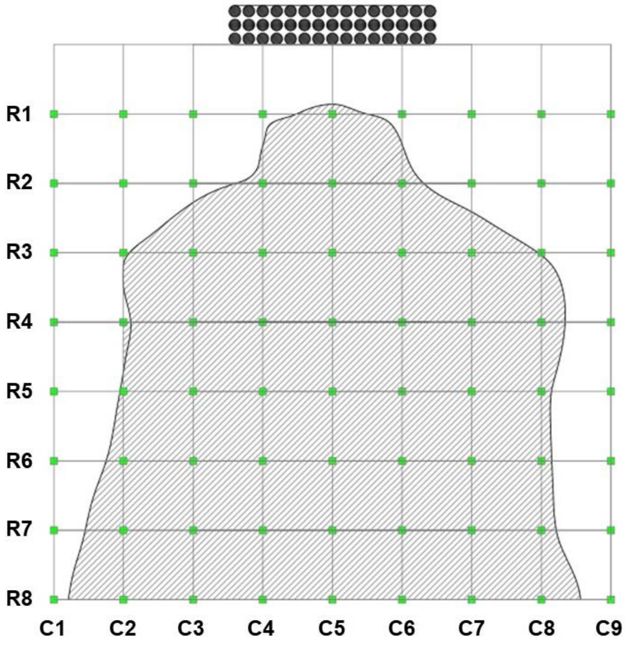

Fig. 9. The result of Limiting the Area That Has a Sound Pressure Level Below 64.70 dB

The area in Figure 9 with a sound magnitude value of less than 64.70 dB is shaded. There is hardly any sound below 64.70 dB in the space 1 meter after the sonic crystal. There are also a few spots where the sound level is lower than 64.70 dB near the test field's boundary, precisely 4 meters from the sonic crystal's central axis. The region where sound is dominant only occurs at distances less than 3 meters from the sonic crystal, or 64.70 dB, below. The main sound area below 64.70 dB is located less than 3 meters from the sonic crystal's center in the area with a horizontal axis. The relationship between the length of the sonic crystal and the region with a sound level below 64.70 dB is calculated using the length of the sonic crystal and the area.

The house by the side of the road is the example implementation used. Assume the type of home is 6 meters wide and 10 meters long. Because it adheres to Indonesian building boundary line regulations, the dimensions of the house are assumed to be 7 meters or 3 meters indented from the front land's boundary. Several factors determine the building boundary line, but we take that 85% of the land for development is permitted. In addition, Indonesia has road border regulations. Therefore, the city layout plan determines the road demarcation line. As a result, it is assumed that the building protrudes 3 meters from the front land boundary following Indonesian building and road boundary regulations. Sonic crystals will then be used to reduce noise. The result requires the length of the sonic crystal of this research. Therefore, 3 meters for a home with a width of 6 meters. The application of the sonic crystal is demonstrated in the following illustration.

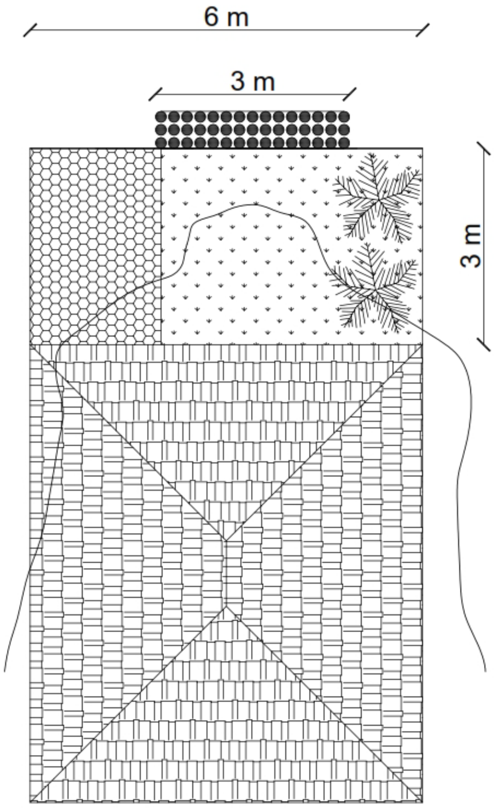

Fig. 10. Illustration of Sonic Crystal Implementation In a Home

Figure 10 shows how sonic crystals are used in a home with a 6-meter width. The sonic crystal is situated 3 meters from the structure in the ideal location. This is supported by the study's findings, which indicated that the 3-meter position after the sonic crystal dominated the necessary sound attenuation. As a result, the 3-meter-long sonic crystal is constructed to defend the region inside the house. The house is also accessible from the street with a 3-meter sonic crystal length.

In this study, the insertion loss ability of sonic crystals with PVC material was an average of 16.90 dB. According to [9], highway noise can reach 80 decibels. Meanwhile, [2] specifies a sound threshold of 55 dB. As a result, the sound can only be muted up to 63-64 decibels. Every house, however, must have walls. According to [6,] walls can reduce sound by up to 15 decibels so that the sound heard by people due to sonic crystals and barriers are less than 55 decibels. This combination allows the sound to drop below a predetermined sound threshold.

5 CONCLUSIONS

Sonic crystal characterization has been completed under actual usage and in the open field to identify the significant insertion loss. This study describes and demonstrates the use of sonic crystals in an open area. This research will connect sonic crystal structure research with future sonic crystal applications. An average Insertion Loss value of 16.90 dB was obtained using a 6-inch square lattice PVC material in a real-scale sonic crystal study under field settings. In the sonic crystal testing point's fifth row and fourth column, the highest IL attained was 21.57 dB. The sound contour map results from this research using the SURFER application. According to the research findings and the sound contour map, the sonic crystal should be placed 3 me-ters away from the building. Combining sonic crystals and house walls demonstrates that the sound attenuation results can reach a predetermined sound threshold. Due to the effects of transportation, it can serve as a guide for placing sonic crystals in residential areas.

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Paper submitted: 05.01.2023.

Paper accepted: 03.08.2023.