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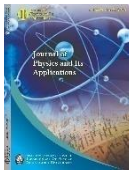

Effectiveness of Noise Barriers Based on Waste Materials in Case Study of Residential Noise Due to Double-Track Railways

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A B S T R A C T

The noise pollution in residential areas adjacent to double-track railways can significantly disturb the comfort and well-being of residents. The noise originates from passing trains on these double-track railways. The research problem aims to compare the noise levels in the residential area with the standard noise threshold and evaluate the effectiveness of a noise barriers based on waste material called sustainable noise barrier. The effectiveness of reducing noise levels for communities residing near the dual railway lines. The sustainable noise barrier is constructed using waste cardboard and sawdust as sound absorbers for reducing noise from passing trains. The objective of the research is to analyze the noise levels in the residential areas near the dual railway lines, referring to the noise threshold value specified in Kep.MenLH No.48 of 1996, which is 55 dBA. Additionally, the research aims to assess the effectiveness of the sustainable noise barrier in mitigating noise pollution in these residential areas. The research employs a quantitative experimental method, following the SNI 8427 of 2017 standard for measuring residential noise pollution and determining the sustainable noise barrier's effectiveness using Insertion Loss (IL) and Sound Transmission Loss (STL) measurements in both laboratory-scale and existing conditions (alongside the double-track railways). The research findings indicate that the noise levels in residential areas adjacent to dual railway lines exceed the threshold value, reaching 78.08 dBA. However, the sustainable noise barrier proves to be effective in reducing noise pollution by 27 dB at a frequency of 1,000 Hz in the residential areas neighboring the double-track railways. This research suggests that limiting noise disturbances in residental areas bordering railway lines is one solution with noise barriers.

1. Introduction

Double-track railways located in densely populated areas, accompanied by a high volume of train activities passing through, significantly impact the pollution of the surrounding environment. Trains contribute to pollution through various sources, with noise pollution a prominent issue. The noise pollution originates from the train's propulsion system, auxiliary system, and the interactions between the train wheels and the track surface [1]. If not properly controlled, this noise can severely disrupt the comfort and well-being of the residents living around the railway crossings [2].

One important aspect highlighted in this research problem is the environmental conditions surrounding the dual railway lines near the densely populated residential areas. This situation leads to a high level of noise disturbance that significantly impacts the comfort and health of the local residents [3]. Supported by Krismayanti's research in 2022, an analysis of noise in the area around the Winongo Kota Madiun double-track railways showed that the noise levels near the population exceeded the permissible threshold, measuring 75 dB(A) at a distance of 21 meters from the center of the tracks, while the allowable point is 55 dB(A) [4]. Additionally, Shahidan's 2017 study stated that conventional diesel locomotives produce the highest noise levels [5]. This necessitates measures for preventing and protecting the community from the negative effects of noise pollution [6]. One solution to mitigate the noise impact caused by passing trains is to control the noise level using noise barriers [7]. These barriers are designed to dampen and reduce the noise transmitted from the railway lines to the surrounding residential areas, thus providing a more comfortable living environment for the local residents.

In this research, a noise barrier is designed and constructed using a mixture of waste cardboard and leftover wood sawdust combined as a sound propagation medium. The utilization of this waste material serves as a way to repurpose and recycle materials from previous usage. By recycling these waste materials, they are transformed into a noise barrier structure, making their usefulness sustainable [8]. The effectiveness of the noise barrier is then measured from two aspects: its dimensions using the Insertion Loss measurement method and its material using the Transmission Loss measurement method [9]. The measurements are conducted on two scales: in the laboratory and directly at the railway track's edge.

Previous research has primarily focused on measuring noise levels, and some studies have explored the capabilities of specific materials [9]. Therefore, this current research intends to integrate both aspects by investigating noise measurements and mitigation through a noise barrier that utilizes waste materials. The study aims to analyze the level of residential noise pollution caused by dual railway lines in comparison to the thresholds specified in Decision of Minister 48 of 1996 set the residential noise threshold at 55 dBA, and this study measured the noise level of the residental areas when it is adjacent to the double-track railways. Additionally, the research aims to assess the effectiveness of the constructed noise barrier in reducing noise levels from two perspectives: its dimensions and the materials used.

By combining these two aspects, the research aims to provide a comprehensive understanding of the noise pollution problem caused by the dual railway lines and the potential solution offered by the sustainable noise barrier. The analysis of noise pollution levels will offer insights into the extent of the issue and its implications for nearby residents, while the evaluation of the noise barrier's effectiveness will shed light on its capabilities in mitigating the noise pollution problem. Ultimately, this research aims to contribute valuable knowledge and practical solutions to address the adverse effects of noise pollution in the vicinity of dual railway lines by implementing sustainable noise barriers.

2. Methods

Initial Noise Measurement

Research begin with the initial noise measurement in the Graha Kirana Housing Complex, Winongo, Madiun City, which is directly adjacent to the dual railway lines. The initial noise measurement in the residential area followed the guidelines of the Indonesian National Standard (SNI) 8427 of 2017, which regulates the measurement of environmental noise levels [10]. Three data collection points were selected for the measurement: point 1, located directly facing the noise source (16 meters from the center of the tracks); Point 2, positioned facing the main road within the housing complex (32 meters from the center of the tracks); and point 3, situated away from the main road within the housing complex (100 meters from the center of the tracks). Data collection points are shown in the figure 1.

Fig 1. Residential noise data collection points

A Sound Level Meter (SLM) was used for the noise measurement, placed at a height of 1.2 to 1.5 meters from the ground is useful to avoid the reflection of the recorded sound and using an A-weighting frequency response. The measured noise was primarily from passing trains, and data were recorded at intervals of 5 seconds in accordance the Decision of Minister 48 of 1996. The study also considered other factors that could influence the measurements, such as weather conditions, wind speed, and humidity. The purpose of this initial noise measurement was to establish baseline data on the existing noise levels in the residential area caused by passing trains. This data serves as a reference for evaluating the effectiveness of the noise barrier in mitigating noise pollution in the subsequent phases of the research.

Construction of *Sustainable Noise Barrier*

The noise barrier construction involves using waste cardboard as the primary material, which is cut into pieces and soaked in water until it becomes soft. The soaked cardboard is then blended to a pulp-like texture and squeezed using the cloth to reduce the moisture content. To the pulp mixture, wood sawdust is added in a 1:3 ratio with the recycled cardboard. This comparison is used for the composition of noise barrier materials focused on cardboard waste and sawdust waste as a mixture. The mixture is combined with wood glue as an adhesive and then molded into block shapes. These blocks are then dried under sunlight until fully dried. The dried blocks of the sustainable noise barrier can be seen in Figure 2.

Fig 2. The dried blocks of the sustainable noise barrier

The dried and sun-dried noise barrier blocks are then assembled using wire and galvalume steel frames to form blocks measuring 1 meter x 1 meter. The back of the noise barrier is covered with used PVC ceiling panels (recycled) to seal the gaps and prevent sound from passing through open spaces. The front and back views of the sustainable noise barrier can be seen in Figure 3 (a) and (b), respectively.

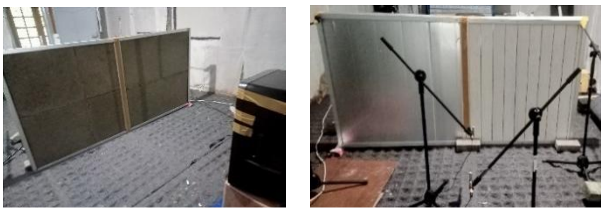
(a) (b)

Fig 3. *Sustainable noise barrier* (a) front view dan (b) back view

The dimensions of the noise barrier are determined based on the positioning between the noise source (railway track) and the receiver (residential area). The noise barrier is placed at a distance of 8 meters from the railway track (source) and 5.5 meters from the residential area (receiver) with a height of 1 meter. However, due to the presence of a 1-meter-high existing boundary structure at the noise barrier's placement location, the noise barrier's height is adjusted to 2 meters from the ground when installed.

Measurement of the Sustainable Noise Barrier in Laboratory Scale

The measurement of the noise barrier at the laboratory scale was conducted in the Physics Department of the Sepuluh Nopember Institute of Technology. The measurement methods used were Insertion Loss (IL) and Sound Transmission Loss (STL). The use of the insertion loss method is useful for characterizing noise barriers from the source and receiver sides, while the transmission loss method is useful for characterizing noise barriers in its materials. The IL measurement was carried out in a Semi-Anechoic Room, which is a room designed to minimize sound reflections, ensuring accurate measurements of the noise barrier's performance. On the other hand, the STL measurement was performed between the Reverberation Room (as the sound source) and the Semi-Anechoic Room (as the receiving room). In this setup, a speaker was used as the noise source, and a microphone was employed to capture the transmitted sound data, which was then recorded on a computer for analysis. The positions for the Insertion Loss (IL) measurement can be seen in Figure 4 (a) and (b).



(a) (b)

Fig 4. Measurement insertion loss (a) source position and (b) receiver position

In Figure 4 (a), the IL measurement is shown from the source side, which directly faces the noise barrier. Figure 4 (b) depicts the IL measurement from the receiving side in the Semi-Anechoic Room. The IL measurement represents the noise level or intensity before and after the noise barrier installation. The difference between the noise level before the noise barrier is installed and after its installation gives the IL value of the noise barrier.

The STL measurement is conducted between the Reverberation Room (as the sound source) and the Semi-Anechoic Room (as the receiving room). The STL measurement assesses the noise barrier's ability to attenuate and block sound transmission between these rooms. The STL measurement data can be seen in Figure 5 (a) and (b).

Fig 5. Measurement *sound transmission loss* (a) source position dan (b) receiver position

In Figure 5 (a), the STL measurement is shown from the Reverberation Room (as the sound source) using a speaker as the noise source. Figure 5 (b) depicts the STL measurement in the Semi-Anechoic Room (as the receiving room) using two microphones to capture the transmitted sound data, which is then recorded on a computer for analysis. Unlike the IL measurement, which assesses the noise level before and after the noise barrier installation, the STL measurement evaluates the material's sound reduction capability. The STL measurement involves using two microphones, one in the sound source room (Reverberation Room) and the other in the receiving room (Semi-Anechoic Room). The transmitted sound from the sound source room to the receiving room is measured to assess the noise barrier's ability to attenuate and block sound transmission.

Measurement of the Sustainable Noise Barrier at Existing Scale

The measurement of the noise barrier at the existing scale is conducted directly at the edge of the dual railway lines, adjacent to the residential area. The noise barrier is positioned at a distance of 8 meters from the railway tracks (noise source) and 5,5 meters from the noise barrier to the receiver (residential area). For this existing-scale measurement, the Insertion Loss (IL) method is utilized, with passing trains serving as the noise source. The IL measurement assesses the noise reduction performance of the noise barrier when exposed to real-world conditions with actual train traffic. The positions for the IL measurement at the existing scale can be seen in Figure 6.

Fig 6. The positions for the Insertion Loss (IL) measurement at the existing scale

In Figure 6, it can be observed that a train is passing directly in front of the noise barrier. Two microphones are placed in parallel, where Microphone 1 faces the noise source (the passing train), and Microphone 2 faces the noise barrier. During the measurement, two different conditions are considered with the same noise source. The first condition involves measuring the noise level without the noise barrier, and the second condition consists in measuring the noise level with the noise barrier in place. The difference between these two measurements represents the Insertion Loss (IL) value for the existing-scale measurement.

3. Result and Discussion

Noise Pollution in Residential Areas Adjacent to Double-Track Railways

The measurement of noise pollution in residential areas around double-track railways was conducted at three different points with varying distances. The results of the noise measurements are shown in Table 1.

Table 1. The results of the noise pollution measurement in residential areas caused by the double-track railways

Measurement Points	Daytime Noise (Ls)	Daynighttime (Lm)	Day and Night time Noise (Lsm)
1 (16 meter)	70,1 dBA	68,5 dBA	78 dBA
2 (32 meter)	65,5 dBA	62,9 dBA	72,5 dBA
3 (100 meter)	51,7 dBA	47,7 dBA	57,6 dBA

In Table 1, the results of noise measurements at three different points with varying distances from the noise source are presented. Based on the data obtained, the highest noise level recorded during daytime and nighttime is at Measurement Point 1, with a value of 78 dBA. The noise level at Measurement Point 2 is 72.5 dBA, while at Measurement Point 3, it is 57.6 dBA. This variation in noise levels is attributed to the phenomenon of distance attenuation, where the farther the measurement point from the noise source, the lower the measured noise value [11]. The data is obtained from the accumulation of noise measurements adjusted to the formula set in accordance with Indonesian National Standard 8427:2017 on Measurement of Environmental Noise Level.

Furthermore, the difference between daytime and nighttime noise levels is an interesting observation. It is evident that daytime noise tends to be higher than nighttime noise [5]. This phenomenon can be influenced by factors such as humidity and temperature. During the nighttime, relative humidity and temperature are generally higher than during the daytime. The impact of humidity on sound is because humid air tends to be denser than dry air, affecting the speed of sound propagation [12].

When compared to the Environmental Ministerial Decree No.48 of 1996, the results of the noise measurements in the residential area exceed the permissible noise limit of 55 dBA. This indicates that the noise pollution around the double-track railways in the residential area is higher than the allowed noise threshold [13].

The Results of the Laboratory-Scale Measurement of the Sustainable Noise Barrier

Based on the measurements of the sustainable noise barrier's effectiveness at the laboratory scale using the Insertion Loss (IL) and Sound Transmission Loss (STL) methods, the laboratory-scale data is used to compare with the measurements conducted at the existing scale. Conducting measurements in the laboratory provides a controlled environment that allows for more specific characterization of sound and minimizes disturbances that may occur during direct on-site measurements at the existing scale.

The IL measurement results are obtained by calculating the difference in noise levels before and after the noise barrier installation [14]. As shown in Figure 7, the IL graph illustrates this difference, indicating the noise reduction achieved by the noise barrier in the laboratory setting.

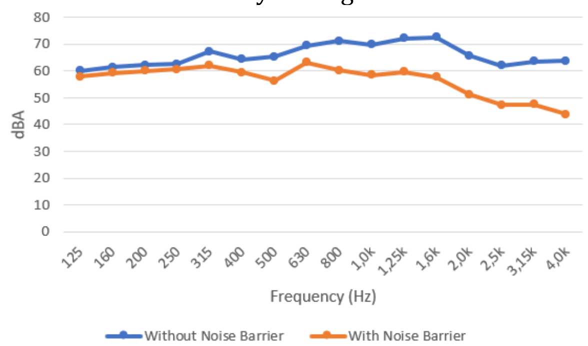


Fig 7. Comparison of sound measurement before and after noise barrier laboratory scale

In Figure 7, the results of the measurements without the noise barrier and with the noise barrier are displayed. The graph in figure 7 illustrates the noise levels before the noise barrier installation (orange line) as higher compared to the noise levels after the noise barrier is installed (blue line). This observation indicates that there is a reduction in noise from the source when the noise barrier is present. The difference between these two measurements represents the Insertion Loss (IL) value, which is shown in Figure 8.

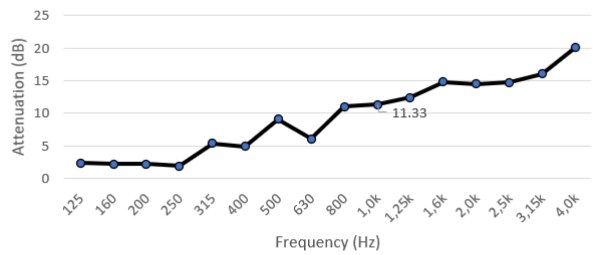


Fig 8. Graph of insertion loss measurement at laboratory scale

In Figure 8, the results of the Insertion Loss (IL) measurement at the laboratory scale are displayed. The data shows that at a frequency of 1000 Hz, the Insertion Loss value is 11.33 dB. The 1000 Hz frequency reading selection is based on human auditory sensitivity, which is most sensitive at around 1000 Hz [15]. Therefore, the sustainable noise barrier constructed in this study has an attenuation value of 11.33 dB at 1000 Hz. The IL measurement quantifies the noise reduction achieved by the noise barrier, and the value obtained indicates the barrier's effectiveness in attenuating noise at specific frequencies. Apart from the IL measurement, the results of the Sound Transmission Loss (STL) measurement at the laboratory scale are presented in Figure 9.

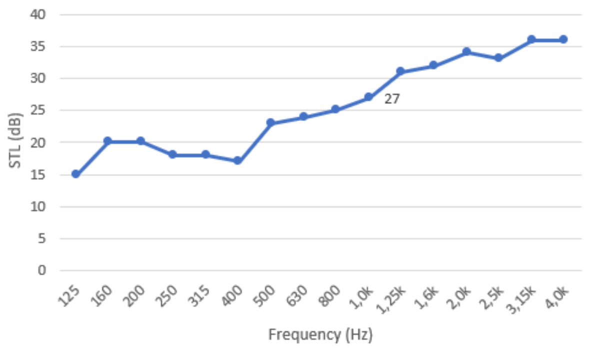


Fig 9. Graph of sound transmission loss measurement at laboratory scale

In Figure 9, the graph displays the results of the laboratory-scale Sound Transmission Loss (STL) measurement. The STL value characterizes the sustainable noise barrier's ability to block and attenuate sound transmission, and in this case, it shows a value of 27 dB at a frequency of 1000 Hz. This indicates that the noise barrier material has the potential to effectively serve as a barrier against noise at that specific frequency [16]. Additionally, the graph demonstrates that the STL values tend to increase at higher frequencies, starting from 1000 Hz. This trend suggests that the material used in the noise barrier is well-suited for attenuating higher-frequency sounds.

Results of the Existing-Scale Measurement of the Sustainable Noise Barrier

The direct on-site measurement of the noise barrier was conducted at the edge between the double-track railways and the residential area. The noise barrier was installed at a distance of 8 meters from the railway tracks and 5,5 meters from the noise barrier to the residential area. This distance is determined based on the distance between the double track railroad and residental areas. The results of the Insertion Loss (IL) measurement, showing the noise levels before and after the noise barrier installation, are presented in Figure 10.

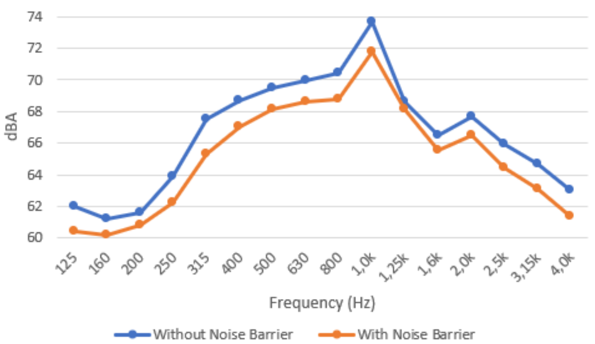


Fig 10. Graph of sound measurement comparison before and after noise barrier installation - existing scale

Based on Figure 10, there is a reduction in sound intensity from the source before and after the noise barrier installation, as measured by two microphones facing directly toward the source (passing trains) and facing directly toward the noise barrier at the same source location. The difference between the sound levels before and after the noise barrier installation represents the Insertion Loss (IL) value at the direct on-site scale, as shown in Figure 11.

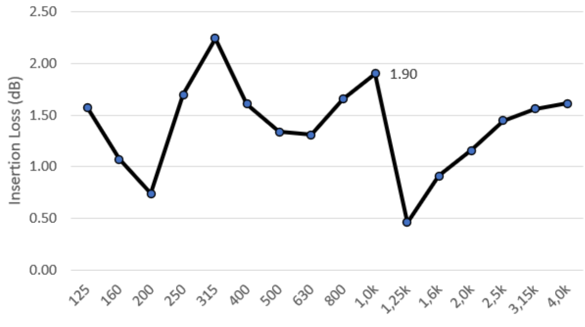


Fig 11. Graph of insertion loss measurement at existing scale

Based on Figure 11, the Insertion Loss (IL) value obtained from the direct on-site measurement at the existing scale is 1,9 dB at a frequency of 1000 Hz [17]. The IL value is influenced by the dimensions of the noise barrier used in conjunction with the passing noise source. In this case, the dimensions of the noise barrier used with passing trains are not proportional. Consequently, the IL value obtained from the on-site measurement is relatively small compared to the IL value obtained from the laboratory-scale measurement. The discrepancy in the IL values can be attributed to the difference in the dimensions and positioning of the noise barrier used in the on-site measurement [18]. The environmental conditions can also influence the results of Insertion Loss [19]. In this research, the noise barrier dimensions used with passing trains may not be optimal for achieving higher noise reduction levels. The effectiveness of a noise barrier is influenced by its dimensions and positioning [20].

4. Conclusion

The residential area adjacent to the double-track railways experiences noise levels exceeding the threshold set by Kep.Men.LH No.48 of 1996, which is 55 dBA. The research findings indicate noise levels at points 1 of 78.08 dBA, 2 of 72.58 dBA, and 3 of 70.31 dBA. The noise barrier built in this study had an Insertion Loss value of 11.33 dB at a frequency of 1000 Hz at the laboratory scale and 1.9 dB for the on-site measurement at the existing scale. However, these results are considered relatively ineffective due to the disparity between the research dimensions and the noise source's magnitude. The effectiveness of the noise barrier is highly influenced by its dimensions, and in this study, the dimensions used may not have been optimized to achieve higher noise reduction levels. The relatively low Insertion Loss values in the on-site measurement suggest that the noise barrier used in the field may not be fully effective in mitigating noise pollution from passing trains. On the other hand, when evaluating the noise barrier's effectiveness based on its material and using the Sound Transmission Loss method, the research yielded a value of 27 dB at a frequency of 1000 Hz. This suggests that the noise barrier made from recycled materials, such as cardboard and sawdust, is effective as a sound insulator.

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