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Environmental Noise Analysis during Pile Driving Using a Single Acting Diesel Hammer

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A B S T R A C T

Pile driving activities using diesel hammers are commonly employed in large-scale infrastructure projects and are known to generate high-intensity impulsive noise that may disturb surrounding environments, particularly residential areas. This study investigates environmental noise generated by pile driving using a single-acting diesel hammer during the construction of an elevated railway line in Kalidengen Village, Kulon Progo Regency, Indonesia. Noise measurements were conducted at distances of 11 m, 110 m, and 160 m from the noise source using a calibrated sound level meter. Ambient noise levels were also measured at the same locations during periods without pile driving activity to ensure accurate assessment of construction noise. The equivalent continuous sound level (L_{Aeq}) was calculated and compared with theoretical predictions based on spherical sound propagation, as well as with the Indonesian environmental noise standard for residential areas. The results show that noise levels near the source exceeded 100 dB(A), while the measured L_{Aeq} values at distances of 110 m and 160 m were 85.77 dB(A) and 77.96 dB(A), respectively, both significantly exceeding the residential noise limit of 55 dB(A). Compared to theoretical predictions, additional sound attenuation of approximately 7.29 dB at 110 m and 11.85 dB at 160 m was observed, indicating the influence of site-specific environmental factors such as vegetation, ground surface characteristics, and partial structural obstructions. These findings highlight the importance of field-based noise measurements for accurate noise impact assessment and support the development of effective mitigation strategies for pile driving activities in residential environments.

1. Introduction

Pile driving of foundation elements is an essential activity in large-scale construction projects such as bridges, high-rise buildings, and elevated railway structures. One of the most commonly used machines for this purpose is the single-acting diesel hammer, which operates by combining gravitational force with diesel combustion to deliver repeated impacts to the pile head [1]. While this method is effective for deep foundation installation, it generates high-intensity impulsive noise that can propagate over considerable distances, particularly when pile driving activities are conducted in close proximity to residential areas.

Impulsive noise produced by heavy construction equipment, including diesel hammers, has been widely reported to adversely affect human health and well-being. Documented impacts include sleep disturbance, increased stress levels, reduced concentration, and potential hearing impairment due to prolonged exposure [3,4]. In addition, the World Health Organization (WHO) has reported that long-term exposure to environmental noise exceeding recommended limits is associated with an increased risk of cardiovascular diseases [5,6].

These findings highlight the importance of systematically measuring and evaluating construction-related noise, especially in residential environments.

Previous studies have investigated various aspects of construction and pile driving noise. Zhou et al. reported that pile driving using diesel hammers can produce sound pressure levels exceeding 110–120 dBA at distances of 10–20 m from the source [7]. Huang et al. developed statistical models to predict noise propagation in urban construction areas and emphasized the need for mitigation measures, such as sound barriers, in densely populated regions [8]. Similarly, the Washington State Department of Transportation (WSDOT) reported that impact pile driving can generate equivalent continuous noise levels (L_{Aeq}) ranging from 95 to 102 dBA at a distance of 15 m, while general construction activities typically produce noise levels between 75 and 100 dBA depending on equipment type and operating conditions [9,10].

In Indonesia, environmental noise limits are regulated through national standards, including SNI 8427:2017, which specifies a maximum allowable daytime noise level of 55 dBA for residential areas [11].

At the international level, WHO guidelines also recommend limiting average environmental noise exposure from rail-related activities to approximately 54 dBA to minimize adverse health effects [12].

Despite the availability of these regulatory frameworks, the practical implementation of effective noise mitigation strategies is often constrained by the limited availability of localized field-based measurement data. In particular, empirical studies describing the spatial characteristics of noise propagation from single-acting diesel hammer pile driving under site-specific environmental conditions—such as residential proximity, vegetation cover, and open agricultural land—remain limited. Many existing studies emphasize numerical modeling, simulation-based prediction, or algorithmic noise control, while fewer investigations provide field-based measurements that directly compare observed noise levels with theoretical propagation models and regulatory thresholds. This limitation can introduce uncertainty in assessing actual noise exposure and evaluating the applicability of commonly used attenuation models in real construction settings.

Therefore, this study investigates environmental noise generated by pile driving using a single-acting diesel hammer during the construction of an elevated railway line in Kulon Progo, Indonesia. Noise measurements were conducted at distances of 11 m, 110 m, and 160 m from the noise source, representing near-field conditions and typical distances of nearby residential buildings. The measured equivalent continuous sound levels (L_{Aeq}) are compared with theoretical sound propagation predictions and evaluated against Indonesian environmental noise standards. To clarify the position and novelty of this work relative to recent studies, a summary of related research published within the last five years is presented in **Table 1**, highlighting the contribution of this field-based investigation under local residential conditions.

Table 1. Related Studies on Construction and Pile Driving Noise

Author (s) & Year	Research Focus	Method & Parameters	Main Findings	Position / Novelty
Li et al. (2021) [10]	Impulsive noise control using active noise control (ANC) algorithms	Numerical simulation of ANC with post-adaptive filter and variable step size	The proposed algorithm effectively reduces impulsive noise and improves convergence performance	Focuses on **algorithmic noise mitigation**, not on field-based environmental noise measurements
Babazadeh et al. (2025) [7]	Predictive simulation of construction site noise from heavy equipment	Integration of BIM, noise mapping, and sensor-based validation	Construction noise emissions can be accurately predicted during the planning phase	Emphasizes **digital simulation and prediction**, rather than detailed diesel hammer noise measurements
Illingworth & Rodkin, Inc. (2020) [6]	Field measurement of pile driving noise in marine construction	Field measurement of sound pressure levels during pile driving operations	High noise levels observed near pile driving activities	Provides **practical field measurement reference**, without detailed spatial attenuation analysis
Washington State Department of Transportation (2020) [8]	Assessment of construction and pile driving noise impacts	Noise impact assessment based on distance and equipment type	Impact pile driving generates high equivalent noise levels in surrounding areas	Focuses on **regulatory and assessment guidance**, rather than site-specific residential measurements
OSHA (2021) [1]	Occupational noise exposure and health risks	Technical guidelines for noise exposure assessment	Prolonged exposure to high noise levels poses significant health risks	Addresses **occupational exposure**, not residential environmental noise propagation
This study (2026)	Environmental noise analysis of single-acting diesel hammer pile driving in residential areas	Field measurement of (L_{Aeq}) at distances of 11 m, 110 m, and 160 m; comparison with theoretical propagation models and SNI 8427:2017 limits	Noise levels at residential distances significantly exceed regulatory limits; theoretical models tend to overestimate measured values	**Field-based empirical study under local Indonesian residential conditions**, evaluating model deviation and regulatory compliance

2. Research Method

2.1. Study Area and Measurement Locations

This study was conducted in Kalidengen Village, Temon Subdistrict, Kulon Progo Regency, Special Region of Yogyakarta, Indonesia. The study area is located in close proximity to the construction site of the elevated railway line connecting Kedundang Station to Yogyakarta International Airport (YIA). Kalidengen represents a residential environment directly exposed to pile driving activities during the construction phase. The surrounding area consists of residential houses, open rice fields, and vegetation, which may influence sound propagation and attenuation characteristics.

Environmental noise measurements were conducted at three observation points selected based on their horizontal distance from the primary noise source, namely the diesel hammer used for pile driving, representing near-field conditions and typical distances of nearby residential buildings from the construction site, located at coordinates −7.897081, 110.082373 at a distance of 11 m (Location 1), −7.897878, 110.081373 at a distance of 110 m (Location 2), and −7.895816, 110.082373 at a distance of 160 m (Location 3).The relative positions of the measurement locations with respect to the pile driving site are illustrated in Figure 1.

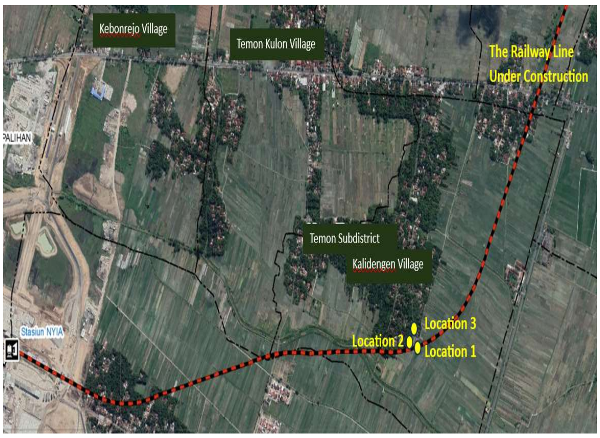


Figure 1. Measurement locations around the pile driving site

2.2. Pile Driving Equipment

Pile driving activities in this study employed a single-acting diesel hammer, specifically the DELMAG D19-42 model. This type of hammer operates by allowing a heavy ram to fall under gravity, followed by the ignition of diesel fuel that generates an additional combustion-driven impact on the pile head. Due to its high impact energy and repetitive operation, this equipment is known to produce high-intensity impulsive noise.

The main mechanical specifications of the diesel hammer are summarized in Table 2. The DELMAG D19-42 has a ram weight of approximately 1,900 kg and a stroke length of 4,200 mm, producing a maximum impact energy of about 78 kNm. The impact frequency ranges between 40 and 60 blows per minute (bpm), resulting in repetitive impulsive acoustic events during pile driving operations. The total weight of the hammer is approximately 3,400 kg and it is operated using a vertical leader guide system to ensure alignment during installation.

Table 2. Mechanical specifications of the DELMAG D19-42 diesel hammer

Parameter	Value
Ram weight	1,900 kg
Stroke length	4,200 mm
Maximum impact energy	±78 kNm
Impact frequency	40–60 bpm
Total hammer weight	±3,400 kg
Guide type	Vertical leader

The measurement points and their immediate surroundings during the pile driving operations are illustrated in Figure 2.

a b

Figure 2. Measurement locations during pile driving operations: (a) Location 1 and (b) Location 2.

2.3. Acoustic Characteristics of the Diesel Hammer

Operation of the DELMAG D19-42 diesel hammer generates high-intensity impulsive noise. Technical documentation and previous measurements indicate that sound pressure levels near the source (approximately 1 m) can reach 115–125 dB(A). At distances of around 10 m, noise levels typically range between 100 and 110 dB(A), decreasing to approximately 85–95 dB(A) at 50 m and 75–85 dB(A) at 100 m. These noise levels frequently exceed recommended environmental noise limits for residential areas.

The dominant frequency components of diesel hammer noise are generally concentrated in the low-frequency range between 31.5 and 250 Hz. Low-frequency noise is more difficult to attenuate through distance or conventional noise barriers. Each hammer impact lasts approximately 0.5–1 s, with repetitive impulses occurring at rates of 35–60 bpm, producing highly impulsive acoustic events that are perceived as particularly disturbing in residential environments.

2.4. Noise Measurement Instrumentation

Environmental noise measurements were conducted using a Lutron SL-4023SD sound level meter, which is a Type 2 instrument compliant with IEC 61672-1 standards. This instrument is widely used for field measurements of environmental and occupational noise.

The sound level meter is equipped with a ½-inch electret condenser microphone and supports A-weighted frequency measurements, which are suitable for evaluating human noise exposure. It provides Fast (125 ms) and Slow (1 s) time-weighted responses, enabling accurate capture of impulsive noise characteristics. The instrument has a measurement range of 30–130 dB(A) and a frequency range of 31.5 Hz to 8 kHz. Calibration was performed before each measurement session using a standard 1 kHz, 94 dB acoustic calibrator to ensure data reliability and traceability. The technical specifications of the sound level meter are summarized in Table 3.

Table 3. Technical specifications of the SL-4023SD sound level meter

Parameter	Specification
Measurement range	30 – 130 dB(A)
Frequency range	31.5 Hz – 8 kHz
Microphone type	½-inch electret condenser
Frequency weighting	A and C
Time weighting	Fast (125 ms), Slow (1 s)
Display	Digital LCD
Calibration	1 kHz, 94 dB sound calibrator
Data storage	SD card (up to 16 GB)
Compliance standard	IEC 61672-1 (Type 2)

2.5. Measurement Setup and Procedure

During measurements, the microphone was positioned at a height of approximately 1.0–1.5 m above ground level, corresponding to the average ear height of a standing adult. To minimize sound reflection effects, the microphone was placed at least 1 m away from reflective surfaces such as walls, poles, or trees.

Noise measurements were conducted during active pile driving operations between 09:00 and 11:00. At each observation point, sound pressure levels were recorded for a duration of 10 min using Fast response mode with a sampling interval of 5 s. Ambient (background) noise measurements were also conducted at the same locations in the early morning before pile driving activities began. The measured ambient noise levels ranged between 50 and 60 dBA, which were significantly lower than the noise levels recorded during pile driving operations. The general noise measurement setup is illustrated in Figure 3.

2 Figure 3. Environmental noise measurement using the SL-4023SD sound level meter

2.6. Data Analysis

Sound pressure level data recorded at each
30 observation point were processed to obtain the equivalent continuous sound level (L_{Aeq}) using Eq. (1):

$$L_{Aeq} = 10\log_{10}\left(\frac{1}{T}\sum_{i=1}^{T} 10^{L_i/10}\right) \quad (1)$$

13
27 where L_i is the sound pressure level (dBA) recorded at the i-th second and T is the total measurement duration in seconds.

The calculated L_{Aeq} values were compared with the Indonesian environmental noise limit for residential areas, which is 55 dBA. In addition, noise levels at the three measurement locations were compared to examine attenuation trends with increasing distance from the noise source.

To evaluate the agreement between measured and theoretical noise attenuation, sound pressure levels at Locations 2 and 3 were predicted based on
5 measurements at Location 1 using the spherical spreading model expressed in Eq. (2):

7
$$L_2 = L_1 - 20\log_{10}\left(\frac{r_2}{r_1}\right) \quad (2)$$

where L_1 is the measured sound level at
7 reference distance r_1, and L_2 is the predicted sound level at distance r_2. This theoretical model assumes ideal free-field conditions without significant reflections or absorption and serves as a simplified reference for evaluating field measurement results.

3. Results and Discussion

25 Pile driving activities using heavy construction equipment, particularly a single-acting diesel hammer, generated substantial environmental noise in the study area. Field measurements were conducted in Kalidengen Village at three distances—11 m, 110 m, and 160 m—from the noise source to evaluate the spatial characteristics of noise
3 propagation during pile driving operations. The measured sound pressure levels at the three locations are illustrated in Figure 4.

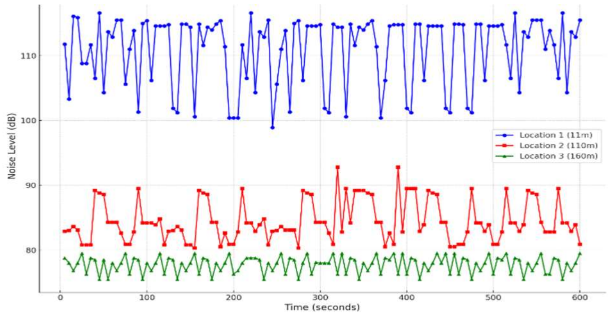


Figure 4. Measured sound pressure levels at distances of 11 m, 110 m, and 160 m from the pile driving source

As shown in Figure 4, noise levels measured at the nearest location (11 m) exhibit repeated high-intensity impulsive peaks exceeding 100 dB(A), which is characteristic of diesel hammer pile driving. These impulses correspond to individual hammer blows delivering high impact energy to the pile head. At greater distances, the noise levels show a clear reduction, reflecting attenuation with increasing distance from the source.

The measured noise levels at 110 m and 160 m demonstrate an overall logarithmic decay trend, consistent with fundamental sound propagation theory, which predicts an approximate 6 dB reduction for each doubling of distance under ideal free-field conditions. However, the attenuation observed in the field deviates from theoretical predictions, indicating the influence of site-specific environmental factors.

3.1. Equivalent Continuous Noise Levels

The equivalent continuous sound level (L_{Aeq}) was calculated using Eq. (1) to represent average noise exposure at each measurement location. The predicted L_{Aeq} values at Locations 2 and 3 were estimated based on the measured L_{Aeq} at Location 1 using the spherical spreading model expressed in Eq. (2). The measured and predicted L_{Aeq} values are summarized in Table 4.

Table 4. Measured and predicted equivalent noise levels (L_{Aeq})

Distance from Source (meters)	Measured (LAeq) (dB A)	Predicted (LAeq) (dB A	Difference (Predicted – Actual) (dB A)
110	85.77	93.06	+7.29
160	77.96	89.81	+11.85

At a distance of 110 m, the predicted noise level exceeds the measured value by 7.29 dB. This difference becomes more pronounced at 160 m, where the predicted value is 11.85 dB higher than the measured noise level. These discrepancies indicate that the simplified theoretical model tends to overestimate noise levels at larger distances. The comparison between measured and predicted L_{Aeq} values at 110 m is illustrated in Figure 5.

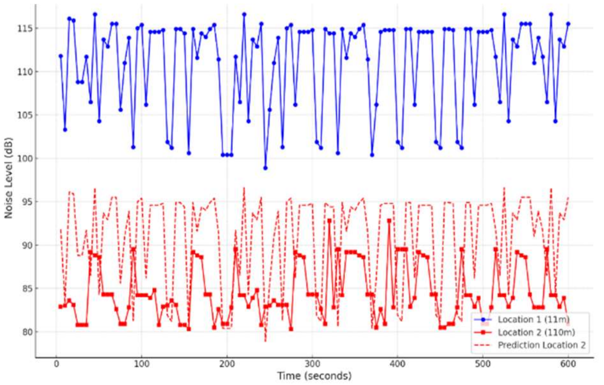
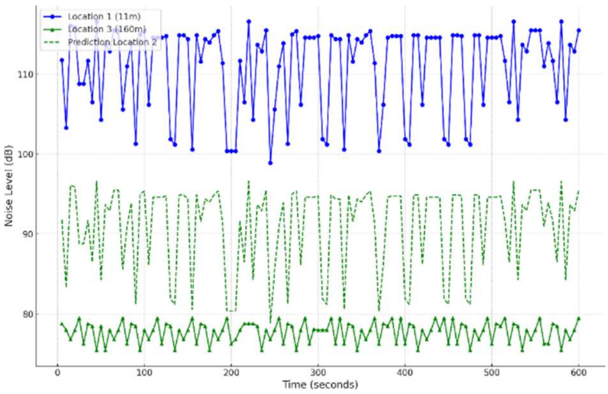


Figure 5. Comparison between measured and predicted L_{Aeq} at 110 m

12 **3.2. Deviation Between Measured and Predicted Noise Levels**

The increasing discrepancy between measured and predicted noise levels with distance suggests that real-world sound propagation differs significantly from ideal free-field assumptions. The theoretical spherical spreading model assumes uniform propagation without accounting for environmental attenuation mechanisms such as ground absorption, vegetation density, atmospheric scattering, and partial obstruction by residential structures. The comparison between measured and predicted noise levels at 160 m is presented in Figure 6.



23 Figure 6. Comparison between measured and predicted L_{Aeq} at 160 m

At longer distances, these attenuation mechanisms become more significant, leading to greater reductions in measured noise levels than predicted by theory. In addition, diesel hammer noise is dominated by low-frequency components, which tend to propagate efficiently over long distances but also experience complex interactions with the ground surface and surrounding vegetation, particularly when direct line-of-sight propagation is partially obstructed.

3.3. Empirical Attenuation Model

To further examine noise attenuation characteristics, an empirical relationship between sound level and distance was evaluated using a logarithmic model expressed in Eq. (3):

$$L_r = a - b\log_{10}(r) \quad (3)$$

22 where L_r is the sound level at distance r, and a and b are regression constants.

A linear regression analysis was performed using $\log_{10}(r)$ as the independent variable and the measured sound level as the dependent variable. Based on the measured data, the following empirical relationship was obtained in Eq. (4):

$$L_{\text{measured}} = 136.51 - 17.13\log_{10}(r) \quad (4)$$

For comparison, regression analysis based on theoretical predictions yielded the following relationship in Eq. (5) :

$$L_{\text{predicted}} = 127.65 - 13.81\log_{10}(r) \quad (5)$$

The comparison of the regression models for measured and predicted noise levels is shown in Figure 7.

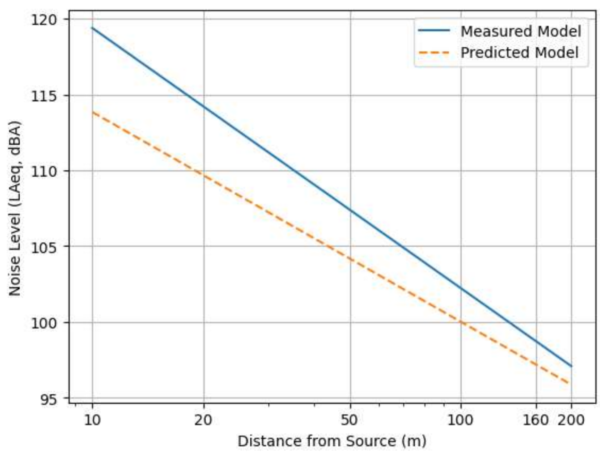


Figure 7. Comparison of linear regression models for measured and predicted noise levels as a function of $\log_{10}(r)$

The measured data exhibit a steeper attenuation slope (−17.13 dB per decade) compared to the theoretical model (−13.81 dB per decade). This result indicates that actual sound attenuation in the study area is stronger than predicted by simplified theoretical assumptions, primarily due to environmental and site-specific factors.

4. Conclusion

This study demonstrates that pile driving activities using a single-acting diesel hammer in Kalidengen Village generate significant environmental noise that extends well into surrounding residential areas. The equivalent continuous noise levels (L_{Aeq}) measured at distances of 110 m and 160 m were 85.77 dBA and 77.96 dBA, respectively, both substantially exceeding the Indonesian residential noise limit of 55 dBA as specified in SNI 8427:2017.

Comparison between measured and theoretical noise levels shows that simplified acoustic propagation models consistently overestimate actual field measurements, with maximum deviations reaching 11.85 dB at a distance of 160 m. This discrepancy highlights the importance of accounting for environmental attenuation mechanisms, including vegetation, ground surface characteristics, and non-ideal propagation paths, when assessing construction noise impacts.

28 The findings of this study emphasize the necessity of field-based noise measurements to support more accurate noise impact assessments and mitigation planning. The results also underline the relevance of applied physics approaches in understanding real-world noise propagation from impulsive construction sources. Implementation of appropriate mitigation measures, such as improved construction scheduling, physical noise barriers, or alternative piling methods with lower noise emissions, is recommended to reduce the impact of pile driving activities on nearby residential communities.

Acknowledgment
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List of Symbols

Symbol	Description
L	Sound pressure level (dB)
L_1	Sound pressure level at reference distance r_1(dB)
L_2	Predicted sound pressure level at distance r_2(dB)
L_{Aeq}	Equivalent continuous A-weighted sound level (dB(A))
L_i	Instantaneous sound pressure level at the i-th sampling time (dB(A))
L_r	Sound pressure level at distance r(dB)
T	Total measurement duration (s)
r	Horizontal distance from the noise source (m)
r_1	Reference distance from the noise source (m)
r_2	Distance from the noise source where sound level is predicted (m)
a	Regression constant representing intercept
b	Regression constant representing attenuation slope

18 6 6 2

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