Assessing the performance of the simple noise chart method for construction noise prediction in earth-moving activity

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Abstract. Construction activity has long been associated with health problems caused by excessive noise exposure from the high noise emission machines. Indeed, predicting noise levels during the planning stages of a construction project can be challenging, particularly when considering complex and dynamic noise sources. This study aims to determine the accuracy and reliability of the simple prediction charts method in predicting construction noise. A case study of piling activity had been conducted at a construction site in Klang valley, Malaysia. The results showed that the average predicted noise levels were slightly higher than the actual measurements, but the highest absolute difference was only 0.9 dBA. The simple prediction charts can approximate the sound pressure level with high reliability with R^2 values of 0.9959. These results show that the simple prediction charts can accurately and reliably predict construction noise levels, providing a useful tool for predicting the noise levels from earth-moving machines at any point of the construction site. With the help of these charts, construction noise practitioners can more easily anticipate and manage potential noise issues.

1 Introduction

Occupational noise exposure is a common risk that affects workers worldwide, particularly those in the construction, mining, and manufacturing industries. In the United States, approximately 22 million workers are at risk of excessive noise exposure [1]. According to a report by Zolfagharian et al. [2], construction noise is the second leading cause of noise pollution in Malaysia. The harmful effects of the noise are intensified by the frequent changes in the mode of construction machines, leading to fluctuations in the noise level [3]. Although the noise produced by construction activities does not significantly affect nearby residents compared to construction workers, it can still lead to psychological disorders due to prolonged exposure to loud noises [4-5]. As reported by the National Institute of Occupational Safety and Health, the noise from machines in the construction industry cause hundreds of thousands of construction workers to experience hearing loss and other noise-related disorders [6]. The major contributors to construction noise are heavy machinery or

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tools, such as nail guns, pneumatic drills, crawler cranes and excavators [7-8]. The excavation stage is particularly loud and plays a significant role in excessive noise levels [9]. In addition, the implementation of noise control measures has been ineffective, leading to construction workers experiencing a range of hearing loss from mild to chronic [10-11].

Noise-Induced Hearing Loss (NIHL) is widespread in Asia, with a prevalence range of 18% to 89%. In Malaysia, healthcare and preventive measures are inadequate to address the substantial number of impacted workers. As such, Malaysia has made significant efforts over the years to improve the health, safety and well-being of workers for the protection of any workplace hazards. The Factory and Machinery (Noise Exposure) Regulations 2019 [12] have been revised to set permissible noise exposure limits and implement control measures in response to the increasing cases of severe NIHL in Malaysia [13]. Employees who work in environments where excessive noise exposure is a concern under the Factory and Machinery (Noise Exposure) Regulations 2019 [12]. The regulations suggest a permissible limit of 85 dBA, and the maximum allowable time duration for noise exposure is 115 dBA, meaning employees should never be in an environment where the noise level exceeds this value. The regulations also limit the peak sound pressure level for impulsive noise to 140 dBA [12].

Precise forecasting of noise levels is crucial in the initial planning phase [14] as it forms a key component of the Environmental Impact Assessment (EIA). The EIA examines the negative impact of construction activities on the environment and provides suggestions to minimize this impact. To effectively mitigate construction noise, it is imperative to have accurate predictions [15-17]. Furthermore, with numerous complaints regarding construction noise being lodged with local authorities, accurate noise prediction methods are crucial in reducing the amount of noise produced by construction works. [18]. The simple prediction charts method was devised by Haron et al. and later researched by Han to improve the accuracy of noise predictions [15, 17]. This method was used to predict the noise level from a complex and dynamic interaction of the construction activity.

The goal of this paper is to verify the performance of the simple noise prediction charts method suggested by Haron [15]. A case study had been conducted at construction sites in Klang Valley, Malaysia. The accuracy and reliability of the method were assessed through the comparison of prediction and measurement noise levels from the case study.

2 Methodology

The research methodology flowchart of this study is shown in Fig. 1 and involved several stages to achieve the aim of the study, such as construction site selection, field measurement, data analysis, and discussion of the findings. In the construction site selection, a case study was chosen to be carried out on-site measurement, and the activity was operating with earth-moving machines. The location of selected construction sites was located in Klang Valley, Malaysia. The construction sites were under piling activity, which is ideal for this study with dynamic noise sources. Also, the chosen construction sites were located in relatively remote areas, which helped minimize the impact of neighbouring noise sources. These sources, such as traffic and nearby construction sites, can greatly affect the accuracy of measurement results. By being situated in rural areas with low traffic volume and a larger land area, the likelihood of additional noise sources being close by was also reduced.

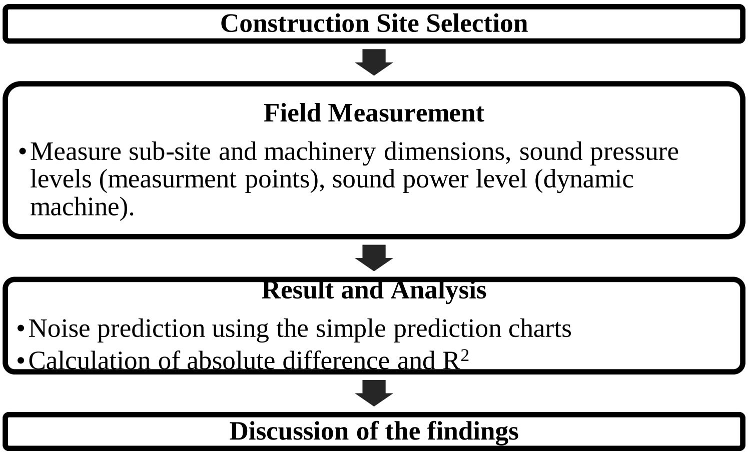


Fig. 1. Research Methodology Flowchart.

The criteria for selecting the case study in field measurement were based on the dynamic noise sources and the duration of their operation. To ensure a comprehensive work schedule, it is necessary to communicate with the machine operators in advance. Activities that were close to completion or had an operating duration that was too brief to meet the minimum recommended noise measurement duration set by the local guidelines on environmental noise [19] were excluded from the selection. Careful consideration must be given to selecting the locations for the control points. The locations must not block other construction activities or be in the middle of a pedestrian walkway. The position of the control points relative to the sub-sites and the distance from each control point to the centre of its respective sub-site is determined through the aid of a distometer. Soundtrack LXT® sound level meter was used to measure the noise data for fifteen minutes at each control point, including equivalent continuous sound pressure level (L_{Aeq}), maximum and minimum sound levels (L_{max} and L_{min}), peak noise level and noise percentiles (L_{10} and L_{90}). The sound power levels for the machinery were also measured during the field measurement. The method of sound power measurement has complied with the BS ISO 3744:2008 [20].

In data analysis, the simple noise prediction chart method was used to predict the noise levels at the control points. The theory and procedure of the prediction had been explained in detail in this article [15, 17]. Fig. 2 shows the site configuration for receiving position and positioned angle to the subarea of an activity. This method was established with mean level deviation, ΔL and standard deviation, σ charts based on different angles (0°, 15°, 30°, and 45°) and subarea aspect ratios (1:8, 1:4, 1:2, 2:1, 4:1, and 8:1). Fig. 3 shows the mean level deviation and standard deviation charts for the aspect ratio 1:2. After obtaining all the parameters from the field measurement, the standard deviation and mean level deviation can be determined using the simple prediction charts. Then, by using the sound power level of the earth-moving machine and the ΔL obtained from the chart, the noise level can be calculated using equation 1.

$$L_p = L_w - 20log_{10}(r) - 8 + \Delta L \tag{1}$$

where
$L_w =$ Sound power level, dBA
$r =$ Distance between the receiving location and the centre of the subarea, m
$\Delta L =$ Deviation of mean level, dBA

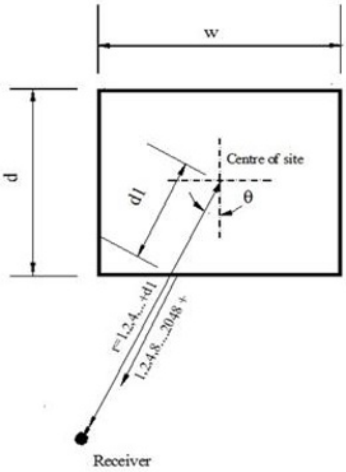
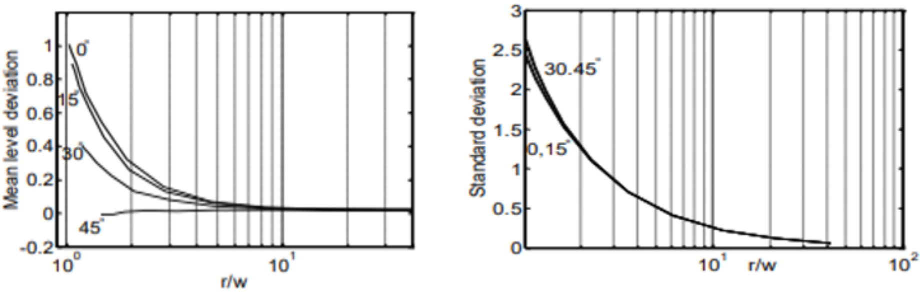


Fig. 2. Subarea Configuration with the Receiver Located at an Angle relative to the Subarea [15].



(a) (b)

Fig. 3. (a) Mean Level Deviation (*ΔL*) and (b) Standard Deviation versus *r/w* (Aspect Ratio 1:2) [15].

When a receiving location is only impacted by the noise level from a single earth-moving activity, the noise level, L_p will be used as the equivalent noise level, L_{Aeq}. But, when two or more earth-moving activities are operating within the same sub-site, then the computation is required to calculate the L_{Aeq} and average standard deviation, σ. The equations of L_{Aeq} and σ at the receiving location are depicted in Equations 2 and 3, respectively.

$$L_{Aeq} = 10log_{10}(10^{L_{p1}/10} + 10^{L_{p2}/10} + \ldots + 10^{L_{pn}/10}) \qquad (2)$$

where
$L_{p1}, L_{p1}, \ldots L_{pn} =$ The average noise level produced by each earth-moving activity at the receiving location.

$$\sigma = \sqrt{\sigma_1{}^2 + \sigma_1{}^2 + \ldots + \sigma_n{}^2} \qquad (3)$$

where
$\sigma_1, \sigma_2, \ldots \sigma_n =$ The standard deviation of the mean noise level calculated for each subsite.

In this study, the absolute difference is utilized to assess the accuracy of the prediction noise level in comparison to the measured noise level. The equation for the absolute difference is depicted in Equation 4:

$$AD = |L_M - L_P| \tag{4}$$

where
AD = Absolute difference, dBA
L_M = Sound pressure level from the measurement at a single receiving location, dBA
L_P = Sound pressure level from the prediction at a single receiving location, dBA

The reliability of simple prediction models is measured using the squared coefficient of correlation, R^2. This metric calculates the variance between the actual results and the predicted results. The equation for R^2 is depicted in Equation 5:

$$R^2 = \left[\frac{\sum[(L_M - \overline{L_M}) * (L_P - \overline{L_P})]}{\sqrt{[\sum(L_M - \overline{L_M})^2 * \sum(L_P - \overline{L_P})^2]}}\right]^2 \tag{5}$$

where
L_M = Sound pressure level from the measurement at a single receiving location, dBA
L_P = Sound pressure level from the prediction at a single receiving location, dBA
$\overline{L_M}$ = Average sound pressure level from the measurement at all receiving locations, dBA
$\overline{L_P}$ = Average sound pressure level from the prediction at all receiving locations, dBA

3 Results and discussion

3.1 Properties of the Case Study

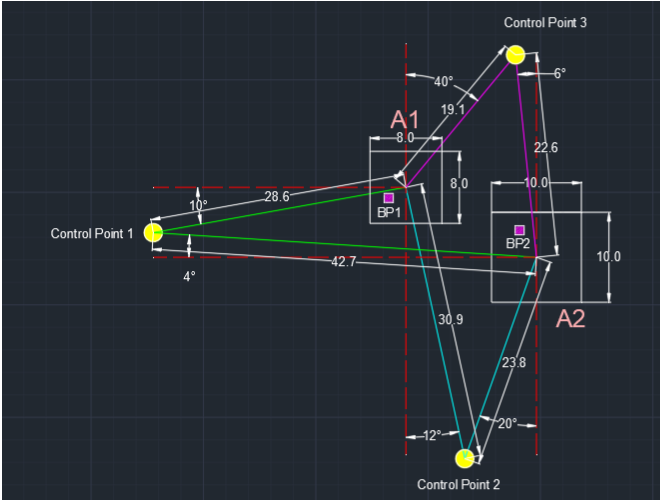
Before the construction work began, the background noise was recorded. The study area was found to have a background noise level of 57.2 dBA. A case study was conducted on the piling activity as shown in Table 1. The case study consisted of two rotary piling drilling machines (BP1 and BP2) with measured sound power levels of 108.9 dBA and 110.8 dBA, respectively.

Table 1. Description of Case Study.

Case Study	Sub-Site	Description
Piling activity	A1 (8 m x 8 m)	The rotary pile drilling machine (BP1) was engaged in drilling a borehole and it was in motion within subarea A1. BP1 sound power level: 108.9 dBA
	A2 (10 m x 10 m)	The rotary pile drilling machine (BP2) was engaged in drilling a borehole and it was in motion within subarea A2. BP2 sound power level: 110.8 dBA

Both rotary piling machines were drilling boreholes and their movement was bounded in the sub-area. Fig. 4 shows the site image and site configurations for the case study, including the dimensions of sub-areas where the noise sources will be moving around within these sub-areas, and the control points surrounding the subareas indicated in the yellow circle. In the case study, two sub-areas (A1 and A2) with an aspect ratio of 1:1 (8m x 8m; 10m x 10m) were recorded to indicate that the rotary piling drilling machines operating areas.

(a) Piling Activity



(b) Site Configurations

Fig. 4. Case Study.

3.2 Measurement versus Prediction

The measurement results at three control points are recorded in Table 2, including the ranges of $L_{\max}$ from 83.3 dBA to 94.7 dBA, $L_{\min}$ from 71.6 dBA to 74.3 dBA, L_{10} from 73.8 dBA to 78.2 dBA, L_{50} from 73.0 dBA to 78.2 dBA, L_{90} from 72.7 dBA to 77.4 dBA, measured L_{Aeq} from 73.5 dBA to 77.8 dBA. According to the results of measured L_{Aeq}, there are no control points exceeding the permissible limits of 85 dBA as stated in local noise regulation [12]. For the prediction results by using the simple prediction chart method, it was predicted that the L_{Aeq} with the standard deviation for control points 1, 2 and 3 are 74.1 ± 0.9 dBA, 76.7 ± 1.2 dBA and 78.5 ± 1.6 dBA. Although the predicted L_{Aeq} were slightly higher than the measured L_{Aeq}, still the values are close to the actual measurement results. The absolute differences for these control points were from the range of 0.6 dBA to 0.9 dBA. For the reliability test, it was found the R^2 with a value of 0.9959 for these control points, as shown in Fig. 5.

Table 2. Measured and Predicted Sound Pressure Levels for Case Study.

Control Point	L_{Max}	L_{Min}	L_{10}	L_{50}	L_{90}	***Measured*** L_{Aeq}	***Predicted*** L_{Aeq}	σ	***AD***
1	94.7	71.6	73.8	73.0	72.7	73.5	74.1	0.9	0.6
2	91.3	72.7	76.4	75.5	75.2	75.8	76.7	1.2	0.9
3	83.3	74.3	78.2	77.7	77.4	77.8	78.5	1.6	0.7

Note: all values with the unit in A-weighted decibel (dBA)

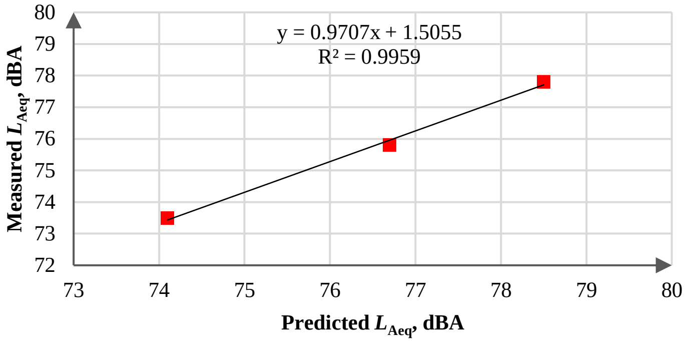


Fig. 5. Measured L_{Aeq} vs Predicted L_{Aeq} for Reliability Test.

These findings indicate that the prediction results are obtained with high accuracy and high reliability. The simple prediction chart method is suitable for predicting noise levels during dynamic activities [16]. However, the accuracy and reliability may be diminished if the machine's movement pattern becomes biased within the sub-area. The ability to accurately predict noise levels from earth-moving machines using simple prediction charts relies on the movement patterns of these machines. In sub-areas where the machine is equally likely to move over each point, this method provides reliable predictions with high accuracy. The design charts offer the benefit of being flexible, allowing the noise level at any point on the construction site to be calculated with ease when it has given the known sound power levels of the earth-moving machines in operation. An accurate and reliable noise prediction method can serve as a planning tool to monitor and control noisy activities at a moderate level.

4 Conclusion

Construction noise generated by earth-moving machines can be a significant problem for nearby areas, and it's essential to predict and manage these noise levels effectively. However, predicting noise levels from these machines is challenging due to the constantly changing noise levels as the machines move around the construction site. As the movement of machines changes, so does the noise output at the receiving locations, making it challenging to predict overall noise levels accurately. This is because the noise produced by the machine will change depending on its location and orientation, making it difficult to predict exactly how loud it will be at any given time. In conclusion, it has been proven that the simple prediction charts could provide high accuracy and high reliability for this study, with the highest absolute difference being only 0.9 dBA and R^2 value of 0.9959, which is close to one. This method is suitable to be applied in the prediction of noise generated by the dynamic noise sound. It could help to monitor and control the dynamic noise at the construction workplace.

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