Malaysian Journal of Civil Engineering 27 Special Issue (1):19-33 (2015)

COMPARISON OF NOISE PREDICTION AND MEASUREMENT FROM CONSTRUCTION SITES

Nadirah Darus, Zaiton Haron* & Khairulzan Yahya

Department of Structures and Material, Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia

*Corresponding Author: *zaitonharon@utm.my*

Abstract: The sound of construction should be reliably predicted at the planning stage, and any mitigation should be implemented not only to avoid excessive noise exposure to the public but also to improve the environmental performance and the process of construction. There are various noise prediction methods that have been practiced by the respected parties. The simplest and most recommended method of noise prediction is the procedure of BS 5228-1:2009. However, previous studies have claimed that this method was inaccurate because of several factors. Therefore, this study attempts to assess the difference between the prediction using this method and the noise obtained from the measurement. The study was conducted by measuring noise emissions from construction activities through selected stations on the earthwork, piling, and structural work, by measuring the individual noise emission of construction equipment, and by predicting noise from construction activities using the measured data. Several related variables were also measured to identify their effects on outdoor sound propagation. Disparities between noise prediction and measurement were checked using a *t*-test. The results showed that all the stations have the significant disparities between prediction and measurement. Apart from the high noise emission level of machines, the highest over prediction (5 dBA) was due to the use of several moving machines during operation processes. Consequently, this affects the distance between the sound source and the measurement station (geometry factor).

Keywords: *Construction noise, noise prediction, noise measurement, construction sites*

1.0 Introduction

The construction industry is a major contributor to economic growth in most developing countries including Malaysia. Construction is a major contributor to the environmental impact and pollution (Fuertes *et al*., 2013). Although many initiatives have been taken to reduce the environmental impact of the construction process, the effect remains the same. Environmental impacts include effects on human health due to the noise of the construction process, among others (Edworthy, 1997; Gannoruwa *et al.*, 2007; Muzet, 2007; Li *et al*., 2010). This is because many plants with loud sound are extensively used without considering the effect on social problems (Manatakis and Skarlatos, 2002).

Construction noise must be reliably predicted at the planning stage (Carpenter, 1997), and any required mitigation should be executed not only to avoid excessive noise exposure to the public but also to improve the environmental performance and construction activity process. Thus, sound is one of the key elements that are subjected to the environmental impact assessment (EIA; Department of Environment, 2007). In this way, the prediction of construction noise will be included in the EIA report, which is provided by an EIA consultant. However, the methods of construction noise predictions vary between different consultants because, currently, there is no established method to be adopted.

The most recommended prediction method for engineers is the BS 5228-1:2009 procedures. However, Carpenter (1997) claimed that the method is not accurate and proposed a stochastic model to simulate noise arising from construction activities. According to Carpenter, it was due to the nature of the fluctuations of the sound coming from the construction process. Previous studies are very limited and not conclusive. This paper studies the noise emissions from construction activities, investigates the individual noise emission level of construction equipment, predicts noise from construction activities, assesses the disparity between the noise level prediction and the measured noise level, and subsequently determines the cause of the disparity between the results.

1.1 Construction Noise

Noise is a set of unwanted sound (Edworthy, 1997; Muzet, 2007; Hamoda, 2008; Fernandez *et al.*, 2009), and from the construction viewpoint, noise is characterised by the level of noise emissions from construction machines, the acoustic noise emission characteristics, the number of machines concurrently in use and the distance between the receiver and the machines, and the condition whether there is obstruction or reflection between the receiver and the machines (Carpenter, 1997; Haron *et al.*, 2009). These include the changes in acoustic power during full or idle working condition (British Standards Institution, 1985; 1997; 2009) and the movement of the machine when working in a workspace.

Construction activities generate severe construction noise since it covers loud operations such as building construction, piling and demolition works (Gannoruwa *et al.*, 2007; Haron *et al.*, 2009). Based on the previous studies, earthworks and excavation stages were the noisiest stage respectively as compared to other stages of construction (Fernandez *et al.*, 2009; Ballesteros *et al.*, 2010; Haron *et al.*, 2012). Furthermore, each stage of construction has different spectrum levels (Ballesteros *et al.*, 2010), so the noise characteristics must be considered in estimating the impact to humans (Department of Environment, 2007). The impacts cannot be detected spontaneously but will escalate in the long-term period. Effects on animals are also not taken lightly because the noise is disturbing the ecosystem where they live.

1.2 Construction Noise Prediction

In the BS 5228-1:2009 procedures, there are four methods of construction noise prediction (British Standards Institution, 2009). The first two methods are for the stationary machine are the methods of activity L_{Aeq} and sound power, and the other two methods are for mobile machines on-site are the methods of on-site (limited area) and hauling in the streets. Basically, noise levels (L_{Aeq}) at the receiver is predicted by combining three basic elements such as acoustic power of the machine, emission model, and propagation models. Figure 1 shows the flow chart for the construction noise predictions as described in Appendix F of BS 5228-1:2009, which take into account several factors, including the sound power machine, the operating facility, the distance between the source and the receiver, the presence of the screening, the reflected sound, and the attenuation due to the earth’s surface.

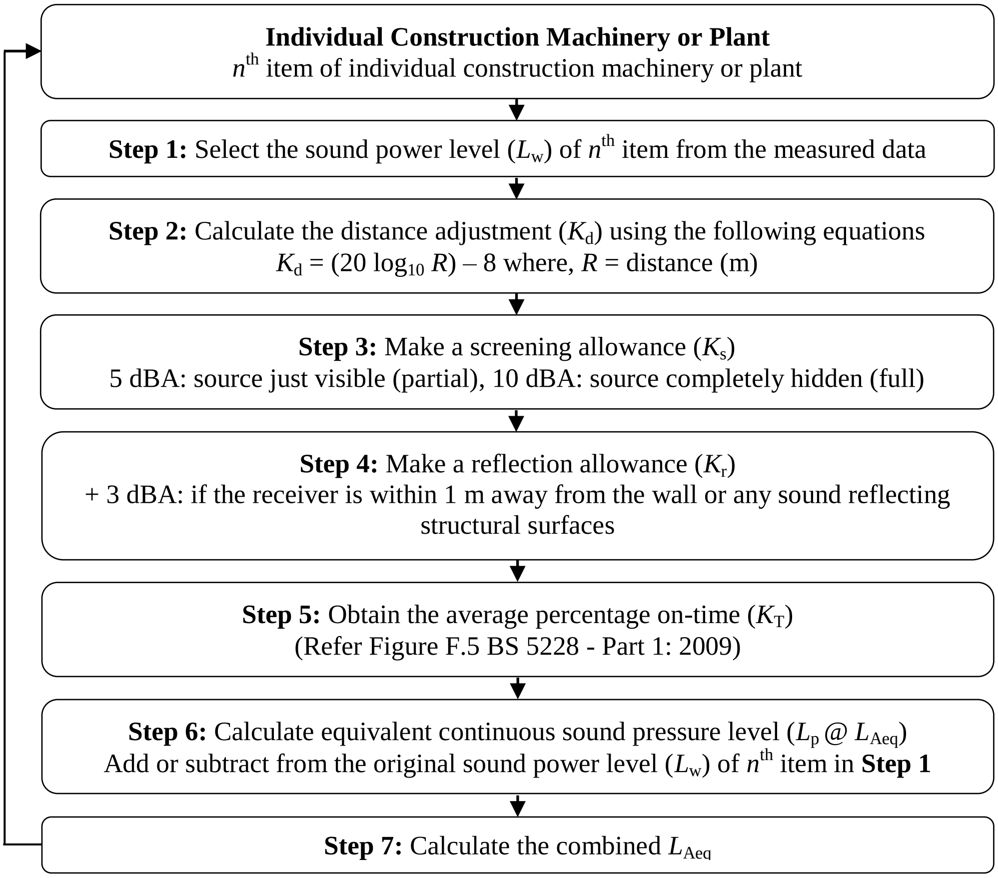


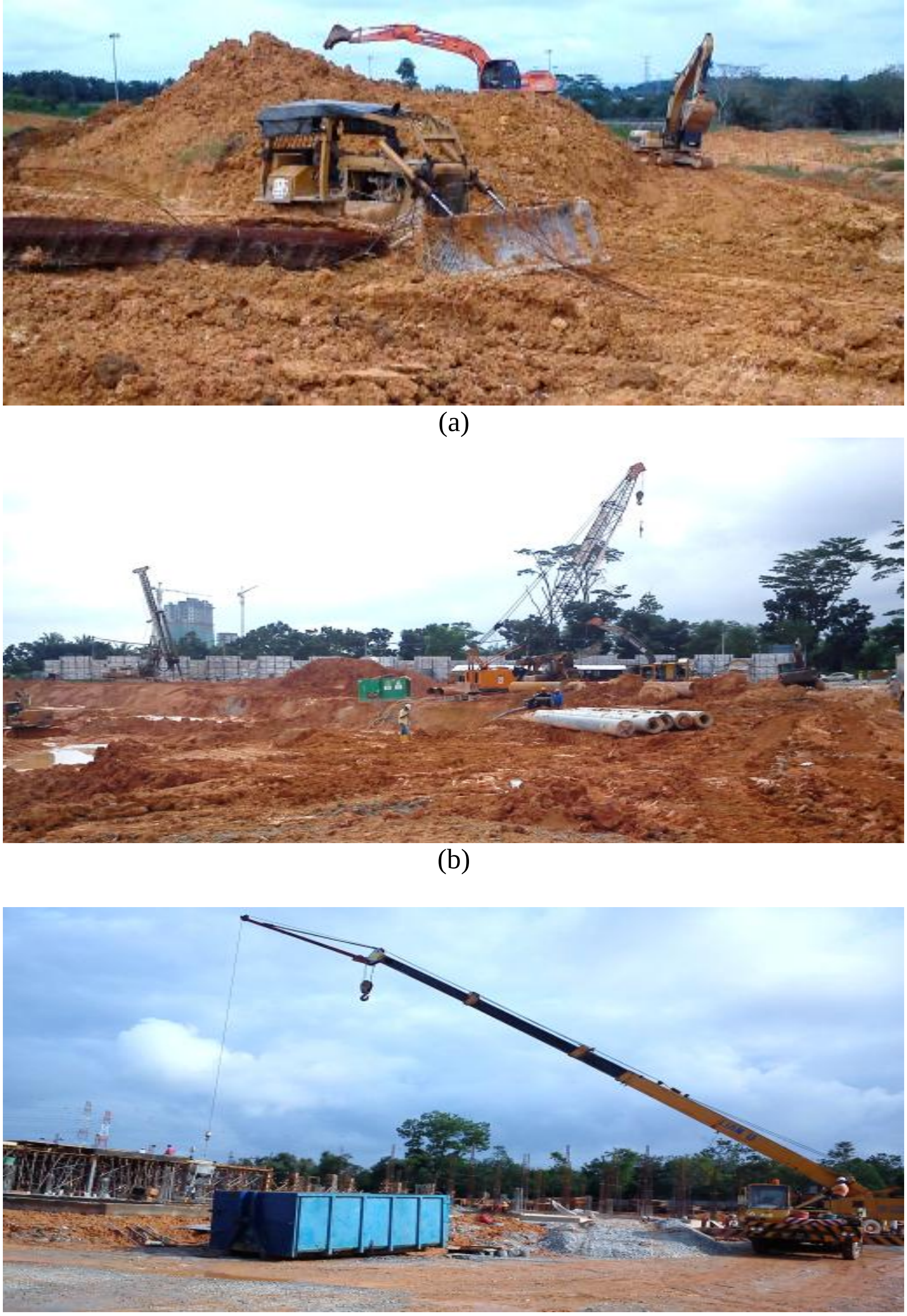
Figure 1: Flowcharts of construction noise prediction using BS 5228 - 1:2009 (British Standards Institution, 2009)

The result of this method is accurate, provided that all the factors mentioned earlier, which are regarded as an input to the model, are accurate. Temperature and wind speed are not included in the BS 5228-1:2009 procedures, unless the distance is greater than 300 m. The wind speed is less than 5 km/hour and also had a great impact on the accuracy of the measurement noise. According to Idris (2012), without obstruction between receiver and operation activities, and also no reflection factor, the noise level of the prediction arising from the two plants (excavator and dump truck) of a small site (50 × 50 m) had an insignificant difference or an over prediction of approximately 1 dBA from the measurement.

However, Jahya (2014) conducted a similar comparison on a larger site and found that, using various plants (five to six plants), there were significant differences in the noise level predictions compared with measurements (an average of 4 dBA, higher than the predicted value) because of the effects of plant movement. Over prediction will be felt by contractors who enter a project tender. Although predictions are used just to get approval or permission from the local authorities, the responsibility for compliance will be transferred to the contractor. The over prediction of L_{Aeq} will result in an excessively high bid price and lessen the chances of gaining the contract (Haron, 2007).

2.0 Methodology

The three construction stages of earthworks, substructure (piling), and superstructure located in Kempas and Skudai, Johor, were chosen as shown in Figure 2. The study was carried out in three phases. Phase 1 involves the measurement noise levels from construction activities (L_{Aeq}), and noise level of individual machines involved in construction activities. Because of safety reasons, the average noise emission level was obtained during the machine working at its full load. The instrumentation used is the sound level meter, anemometer, and distometer, as shown in Figure 3.



(a)

(b)

(c)

Figure 2: Selected construction sites (a) Earthworks, (b) Substructure (piling works) and (c) Superstructure works

(a) (b)

(c) (d)

Figure 3: Required instrumentations (a) Sound level meter - Type 1, (b) Sound level meter - Type 2, (c) Distometer and (d) Anemometer

Measurements were carried out accordingly, as shown in Figure 4, at selected stations for 1 hour with an interval of 15 minutes. Stations are free from objects that give sound reflection and also barriers that can influence the sound transmission. The sound level meter was calibrated before and after measurements, and it was set at 1.2 m above the ground. Noise level (dBA), height of the machine (m), construction noise sources (m), temperature at which the measurement noise (°C), and wind speed measurement stations (m/s) were measured. Measurements were performed at a minimum wind speed and with temperature variation to reduce the differences arising among the predictions and measurements.

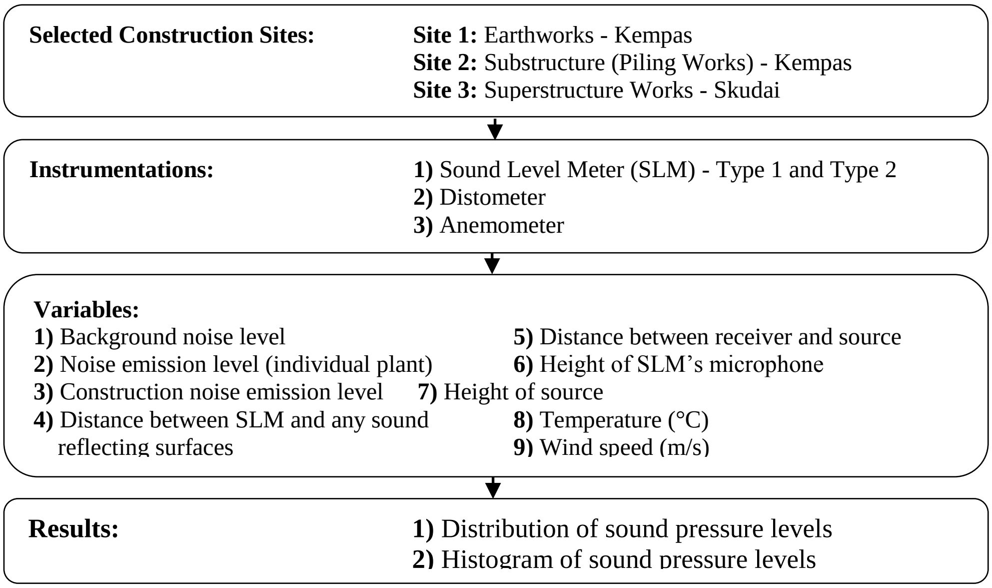


Figure 4: Flowcharts of real on-site construction noise measurements (Phase 1)

Meanwhile, Phase 2 involves the construction noise predictions by using the BS 5228-1:2009 procedures that were carried out for all stations. For this study, the data from Phase 1, that is, the noise emission by individual plant and the average between the receiver and the machine were used. For Phase 3, the disparities of the results of noise prediction and the mean values of measurement for all stations were assessed. A *t*-test as in Figure 5 was conducted to test the significant difference in the mean values of real on-site measurement results and noise prediction. H_0 was rejected if the *p* value was less than 0.05 or if the *t* value from calculation was higher than the *t* value from the *t* table (critical region).

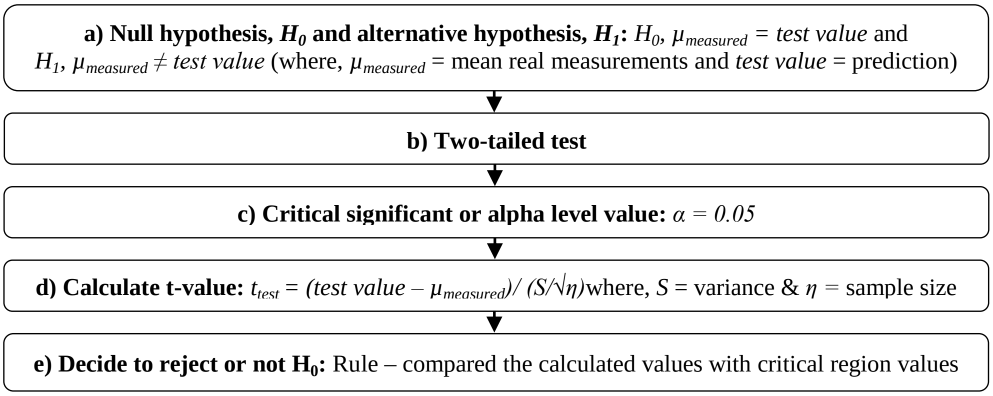


Figure 5: Descriptions of one-sample *t*-test (Phase 3)

3.0 Results and Discussion

3.1 Variables Measured On-Site

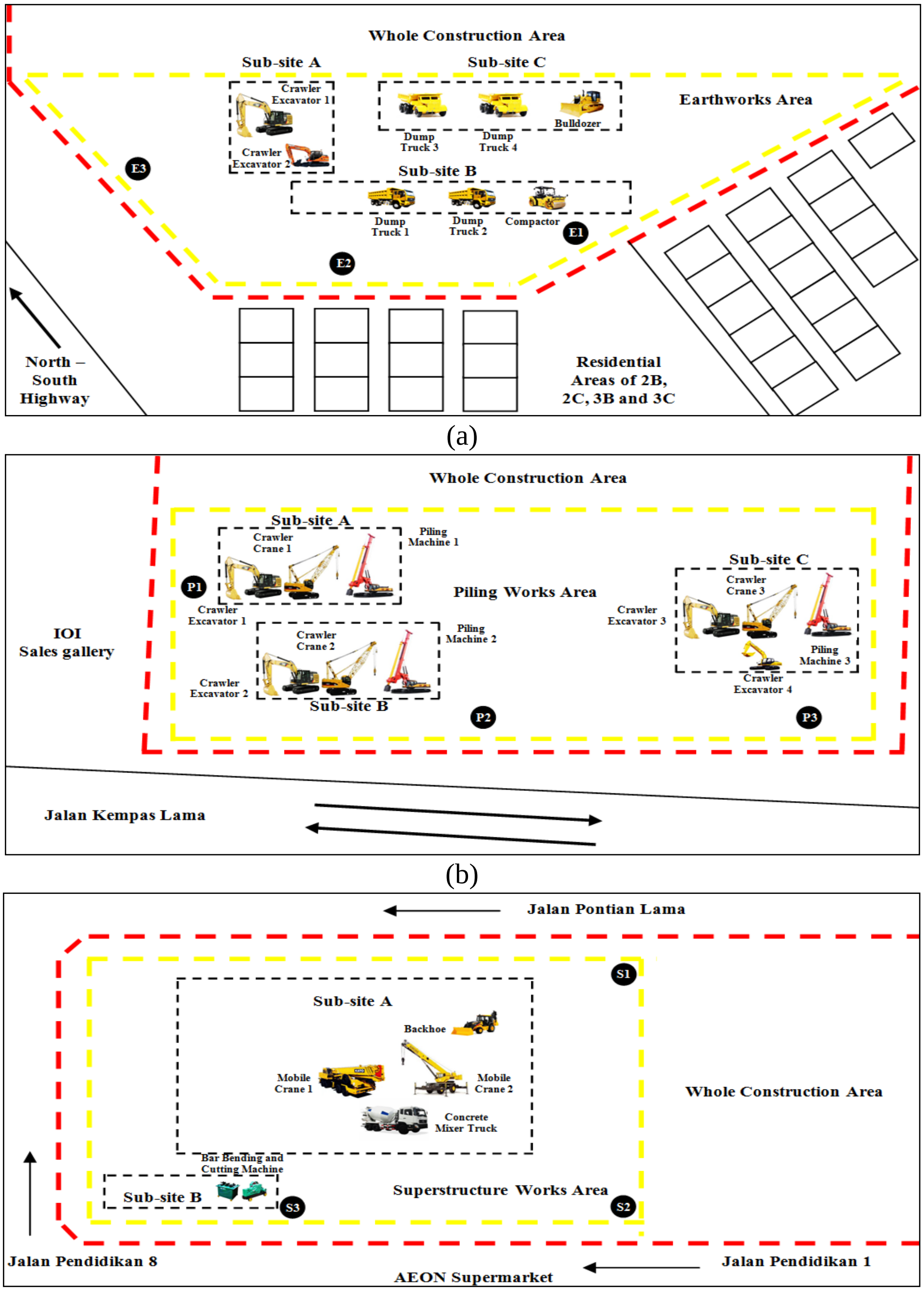
Table 1 shows the values of all variables measured for all measurement stations to identify the variables that affect sound propagation outdoors. It can be seen that the change in wind speed and temperature is relatively small during the measurement.

Table 1: Computation of variables measured on-site

Stages of Construction	Stations	Background Noise Levels (dBA)	Noise Sources (m)	Temperature (°C)	Wind Speed (m/s)
Earthworks	E1	56.20	1.2–2.4	29.8	1.5
	E2	48.90	1.2–2.4	29.6	2.5
	E3	61.50	1.2	30.8	1.8
Substructure (piling works)	P1	66.30	1.2–2.4	27.7	1.5
	P2	63.80	1.2–2.4	32.8	2.0
	P3	61.20	1.2–2.4	31.8	1.8
Superstructure works	S1	53.80	1.2–2.4	32.4	0.5
	S2	55.50	1.2–2.4	33.6	0.7
	S3	60.40	1.0–1.2	29.0	0.5

3.2 Noise Emission Levels from Construction Activities

Figures 6 show the layout of the construction site, including earthworks, substructure (piling), and major structural works. Table 2 summarises the distribution and histogram of the sound pressure level measurement stations. Overall, the highest and the lowest noise emissions were generated from the substructure (piling) and major structural works, respectively. It is caused by several individual machines involved for each construction activity. Meanwhile, the level of noise generated from earthworks is within the range of noise level generated from substructures (piling) and structural works. However, the noise level at station E2 (earthwork) is less than the noise from the installation of the main structure because of the fewer number of individual machines being operated during noise measurement.



(a)

(b)

(c)

Figure 6: Site layouts (a) Earthworks, (b) Substructure (piling works) and (c) Superstructure works

Table 2: Computation of sound pressure levels for 1 hour (5-minute time interval)

Stages of Construction	Stations	Distributions of Sound Pressure Levels (dBA)		Histogram of Sound Pressure Levels (dBA)			
		Highest	Lowest	Range	Highest Frequency of Occurrence	Standard Deviation	Mean
Earthworks	E1	$74.90_{\text{4th 5min}}$	$64.70_{\text{9th 5min}}$	65.00–75.00	70.00–71.00	3.143	70.82
	E2	$69.50_{\text{3rd 5min}}$	$50.20_{\text{11th 5min}}$	50.00–70.00	55.00–60.00	6.225	59.61
	E3	$76.30_{\text{6th 5min}}$	$62.00_{\text{10th 5min}}$	<60.00–>80.00	65.00–67.50	4.809	67.94
Substructure (piling works)	P1	$77.60_{\text{5th 5min}}$	$71.80_{\text{2nd 5min}}$	71.00–78.00	75.00–76.00	1.612	74.94
	P2	$77.60_{\text{6th 5min}}$	$69.60_{\text{12th 5min}}$	68.00–80.00	74.00–80.00	3.401	75.65
	P3	$79.70_{\text{11th 5min}}$	$69.00_{\text{8th 5min}}$	68.00–80.00	78.00–80.00	3.323	75.96
Superstructure works	S1	$67.60_{\text{7th 5min}}$	$59.30_{\text{11th 5min}}$	58.00–68.00	64.00–68.00	3.098	63.72
	S2	$70.20_{\text{3rd 5min}}$	$56.70_{\text{10th 5min}}$	<55.00–>75.00	60.00–61.00	3.899	62.44
	S3	$68.80_{\text{2nd 5min}}$	$57.50_{\text{10th 5min}}$	<58.00–>70.00	67.50–70.00	3.619	65.56

3.3 Noise Emission Levels of Individual Construction Machineries

The results of the measurement of the noise emissions from individual construction equipment were used to calculate their sound power level (L_w) as input data to the noise prediction model. Table 3 shows eight machinery involved in earthwork stages, which includes two crawler excavators, a bulldozer, a dump truck, and four compactors. Meanwhile, ten machines including three machine piling, three crawler cranes, and four crawler excavators were used in the substructure (piling) stage. There are only five machines connected to the main structural works, including two mobile crane, a backhoe, a concrete mixer truck, and a bar bending and cutting machine. The highest and the lowest sound power level (L_w) values were generated from the piling machine of the substructure (piling) (2–115 dBA) and the concrete mixer truck (1–92 dBA) from the structure works, respectively. The individual machine operations for all construction sites have also been summarised in Table 2.

3.4 Construction Noise Prediction Using the BS 5228-1:2009 Procedures

Table 4 shows the construction noise prediction calculations for all measurement stations in the three construction stages. On the basis of Table 3, station E3 produced the highest noise emissions for work related to earthwork because all machines were operated simultaneously. Meanwhile, stations P3 and S3 generated the highest level of noise emissions to the substructure (piling) and major structural works, respectively.

Table 3: Sound power levels and operations of individual construction machineries

Stages of Construction	Types of Individual Construction Machineries	Sound Power Level (dBA)	Types of Machineries Operation
Earthworks	Crawler Excavator, CE 1	108	Excavating the soils
	Crawler Excavator, CE 2	106	Excavating the soils
	Bulldozer, BD 1	101	Dozing the soils
	Compactor, CP 1	98	Compacting the soils
	Dump Truck, DT 1	107	Hauling and dumping the soils
	Dump Truck, DT 2	107	Hauling and dumping the soils
	Dump Truck, DT 3	109	Hauling and dumping the soils
	Dump Truck, DT 4	108	Hauling and dumping the soils
Substructure (piling works)	Piling Machine, PM 1	111	Boring the boreholes
	Piling Machine, PM 2	115	Boring the boreholes
	Piling Machine, PM 3	114	Boring the boreholes
	Crawler Crane, CC 1	101	Installing steel bar and casing
	Crawler Crane, CC 2	100	Installing steel bar and casing
	Crawler Crane, CC 3	99	Installing steel bar and casing
	Crawler Excavator, CE 1	104	Excavating borehole areas
	Crawler Excavator, CE 2	105	Excavating borehole areas
	Crawler Excavator, CE 3	105	Excavating borehole areas
	Crawler Excavator, CE 4	106	Excavating borehole areas
Superstructure works	Mobile Crane, MC 1	99	Installing reinforcement bars
	Mobile Crane, MC 2	109	Pouring concrete for column
	Backhoe, BH 1	98	Lifting strutting for formworks
	Concrete Mixer Truck, CM 1	92	Mixing concrete on-site
	Bar Bending and Cutting Machine, BB 1	93	Bending and cutting steel bars

Table 4: Computation of L_{Aeq} obtained using the BS 5228-1:2009 procedures

Stages of Cons.	Stations	Sub sites	Plants	L_w (dBA)	Distances (m)	Corrections				Individual L_{Aeq}	L_{Aeq} Sub sites	Combined L_{Aeq}
						K_d	K_s	K_r	K_T			
Earthworks	E1	A	CE 1	108	36.5	–39.25	0	0	0	69.75	70.74	73.82
			CE 2	106	20.3	–34.15	0	0	–8.0	63.85		
		B	DT 1	107	56.7	–43.07	0	0	–2.0	63.93	68.05	
			DT 2	107	45.1	–41.08	0	0	0	65.92		
		C	BD 1	101	60.5	–43.64	0	0	–2.0	55.36	67.66	
			DT 3	109	65.8	–44.36	0	0	0	64.64		
			DT 4	108	62.2	–43.88	0	0	0	64.12		
	E2	A	CE 2	106	55.0	–42.81	0	0	–2.5	60.69	60.69	66.31
		B	DT 1	107	50.0	–41.98	0	0	–2.5	62.52	63.78	
			CP 1	98	40.7	–40.19	0	0	0	57.81		
		C	CE 1	108	88.5	–46.94	0	0	–2.5	58.56	58.56	
	E3	A	CE 1	108	45.2	–41.10	0	0	–0.2	66.70	73.04	73.86
			CE 2	106	20.9	–34.11	0	0	0	71.89		
		B	BD 1	101	20.6	–34.28	0	0	–0.5	66.22	66.22	
Substructure (piling works)	P1	A	PM 1	111	42.7	–40.61	0	0	–0.2	70.19	74.23	76.08
			CE 1	104	16.5	–32.35	0	0	0	71.65		
			CC 1	101	37.4	–39.46	0	0	0	61.54		
		B	PM 2	115	55.5	–42.89	0	0	–2.5	69.61	71.49	
			CE 2	105	52.5	–42.40	0	0	0	62.60		
			CE 3	105	40.0	–40.04	0	0	–1.0	63.96		
			CC 2	100	50.0	–41.98	0	0	0	58.02		
	P2	A	PM 1	111	50.0	–41.98	0	0	0	69.02	69.30	78.05
			CC 1	101	55.0	–42.81	0	0	–1.0	57.19		
		B	PM 2	115	30.4	–37.66	0	0	–0.5	76.84	76.84	
		C	PM 3	114	65.0	–44.26	0	0	–1.5	68.24	68.46	
			CC 3	99	60.0	–43.56	0	0	0	55.44		
	P3	B	PM 2	115	90.0	–47.08	0	0	0	67.92	67.92	78.41
		C	PM 3	114	30.6	–37.71	0	0	–0.5	75.79	78.00	
			CE 3	105	23.2	–35.31	0	0	0	69.69		
			CE 4	106	20.3	–34.15	0	0	–1.0	70.85		
			CC 3	99	18.6	–33.39	0	0	0	65.61		

Table 4 (cont'): Computation of L_{Aeq} obtained using the BS 5228-1:2009 procedures

Stages of Cons.	Stations	Sub sites	Plants	L_w (dBA)	Distances (m)	Corrections				Individual L_{Aeq}	L_{Aeq} Sub sites	Combined L_{Aeq}
						K_d	K_s	K_r	K_T			
Super-structure works	S1	A	MC 1	99	30.4	–37.66	0	0	0	61.34	69.45	69.45
			MC 2	109	37.5	–39.48	0	0	–2.5	67.02		
			CM 1	92	40.6	–40.71	0	0	–0.2	51.63		
			BH 1	98	20.5	–34.24	0	0	–0.2	63.56		
	S2	A	MC 2	109	60.5	–43.64	0	0	0	65.36	65.44	65.59
			CM 1	92	49.7	–41.93	0	0	–2.0	48.07		
		B	BH 1	98	90.7	–47.15	0	0	0	50.85	50.85	
	S3	A	MC 2	109	38.1	–39.62	0	0	0	69.38	69.62	69.80
			BH 1	98	44.8	–41.03	0	0	0	56.97		
		B	BB 1	93	28.3	–37.04	0	0	0	55.96	55.96	

3.5 *Comparison of Real On-Site Measurement and Prediction Results*

Table 5 shows the results for all measurement stations construction. The critical *t* value (t $_{\mathrm{critical}}$) for all measurement stations is 1.812. However, the *t* value observed for all measurement stations exceeded the t $_{\mathrm{critical}}$. Therefore, all H_0 were rejected. Thus, the *t*-tests showed that there are significant disparities between the noise level of the actual on-site measurements and the noise prediction results for stations E1, E2, and E3.

Table 5: Test of significant difference in mean equivalent noise levels

Stages of Construction	Stations	Test Value (dBA)	Means, M ($\mu_{measured}$)	No. of Samples(η)	Standard Deviation	*p*	*t*	Test Hypotheses H_0: $\mu_{measured}$ = *test value* H_1: $\mu_{measured} \neq$ *test value*
Earthworks	E1	73.82	70.82	11	3.143	0.010	3.168	H_0 was rejected*
	E2	66.31	59.61	11	6.225	0.005	3.570	H_0 was rejected*
	E3	73.86	67.94	11	4.809	0.002	4.086	H_0 was rejected*
Substructure (piling works)	P1	76.08	74.94	11	1.612	0.040	2.353	H_0 was rejected*
	P2	78.05	75.65	11	3.401	0.042	2.336	H_0 was rejected*
	P3	78.41	75.96	11	3.323	0.035	2.441	H_0 was rejected*
Super-structure works	S1	69.45	63.72	11	3.098	0.000	6.137	H_0 was rejected*
	S2	65.59	62.44	11	3.890	0.023	2.683	H_0 was rejected*
	S3	69.80	65.56	11	3.619	0.003	3.882	H_0 was rejected*

*At a 95% significance level.

3.6 *Discussion of Results Disparity*

On the basis of the previous *t*-test results, all stations at the three stages of construction measurement have higher noise prediction results compared with the results of the actual on-site measurements as in Figure 7. The disparities between the prediction and the measurement *t* values of stations E1, E2, and E3 (earthworks) were 3.00, 6.70, and 5.92 dBA, respectively (an over prediction).

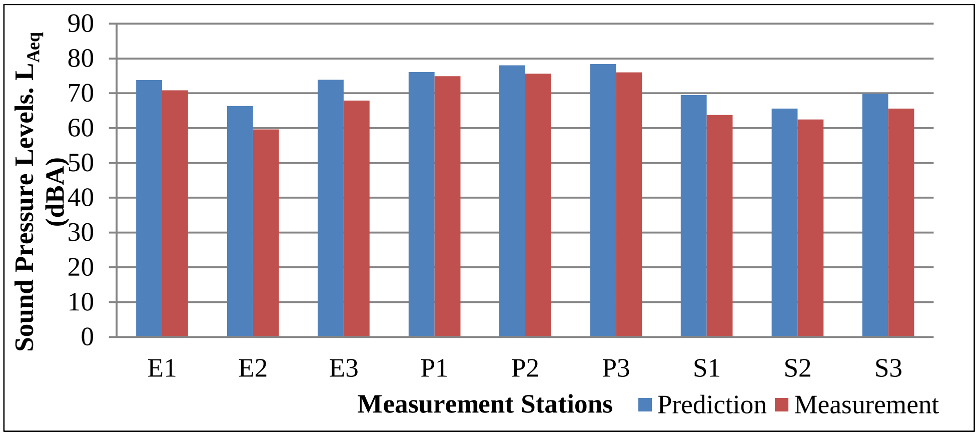


Figure 7: Noise prediction vs. measurement

The result obtained is higher than the previous results obtained by Jahya (2014) because the number of moving machines in this study was more than that of the Jahya study. Meanwhile, for stations P1, P2, and P3 in the substructure (piling) stage, the over prediction values were 1.14, 2.40, and 2.45 dBA, respectively. For stations S1, S2, and S3 in the superstructure works stage, the over prediction values were 5.73, 3.15, and 4.24 dBA, respectively. For *t*-test, the observed values of t_{noise} for all stations were greater than the t_{critical} value of 1.812. Therefore, the hypothesis that measured and predicted noises were equal was rejected. There were significant disparities between real on-site measurement and noise prediction.

It can be seen that the static machines with high noise emission level produced a smaller disparity noise level at the receiver, whereas the construction operation involved several moving plants that produced the largest disparities or uncertainties. The large disparities may be due to a gross simplification in the data input related to the distance between the station and the moving plants. Because the plants have to move around the construction site in real life and because of the level of noise generated from on-site construction equipment, individuals have relied on the variation of the acoustic power of machines during heavy load. In this study, the average acoustic power of machines was used in the prediction.

4.0 Conclusions

In conclusion, this study has evaluated the difference in noise levels predicted using BS 5228-1:2009 procedures and obtained from measurements. Three levels of construction stage have been selected: earthworks, substructure (piling), and structural works. Noise measurements were carried out at several stations at every stage, and noise predictions were calculated accordingly. The *t*-test showed that all stations have significant difference between prediction and measurement. In addition to the high noise emission level of machines, the highest difference (5 dBA) has been shown as the result of the activities that involve several moving machines. Consequently, this affects the distance between the sound source and the measurement station. Therefore, in this study, the difference is caused by the movement of the plant which affects the distance between the sound source and the measuring station (geometry factor), the number of moving machines, and the high levels of machine noise emissions.

5.0 Acknowledgements

The authors would like to express their appreciation for the support of the sponsors with Project No. Q.J130000.2522.03H43 and UTM Zamalah Scholarship.

References

Ballesteros, M. J., Fernandez, M. D., Quintana, S., Ballesteros, J. A., and Gonzalez, I. (2010). Noise emission evolution on construction sites—Measurement for controlling and assessing its impact on the people and on the environment. *Building and Environment, 45*, 711–717.

British Standards Institution. (1985). *BS 5228-Part 1: 2009 Code of Practice for Noise and Vibration Control on Construction and Open Sites*. The United Kingdom: BSI Group Headquarters.

British Standards Institution. (1997). *BS 5228-Part 1: 2009 Code of Practice for Noise and Vibration Control on Construction and Open Sites*. The United Kingdom: BSI Group Headquarters.

British Standards Institution. (2009). *BS 5228-Part 1: 2009 Code of Practice for Noise and Vibration Control on Construction and Open Sites*. The United Kingdom: BSI Group Headquarters.

Carpenter, F. (1997). Construction noise prediction at the planning stage of new developments. *Building Acoustics*, *3*(4), 239–249.

Department of Environment. (2007). The planning guidelines for environmental noise limits and control. Malaysia: Department of Environment Malaysia.

Edworthy, J. (1997). Noise and its effect on people: An overview. *International Journal of Environmental Studies, 51*, 335–344.

Fernandez, M. D., Quintana, S., Chavarria, N., and Ballesteros, J. A. (2009). Noise exposure of workers of the construction sector. *Applied Acoustics, 70*, 753–760.

Fuertes, A., Casals, M., Gangolells, M., Forcada, N., Macarulla, M., and Roca, X. (2013). An environmental impact causal model for improving environmental performance of construction processes. *Journal of Cleaner Production, 52*, 425–437.

Gannoruwa, A. and Ruwanpura, J. Y. (2007). Construction Noise Prediction and Barrier Optimization Using Special Purpose Simulation. *Simulation Conference, 2007 Winter*. 9-12 December. Washington, DC, 2073-2081.

Hamoda, M. F. (2008). Modelling of construction noise for environmental impact assessment. *Journal of Construction in Developing Countries, 13*(1), 79–89.

Haron, Z. (2007). *Probability Approach in Environmental Acoustics*. PhD Thesis. University of Liverpool.

Haron, Z. and Yahya, K. (2009). Monte Carlo Analysis for Prediction of Noise from a Construction Sites. *Journal of Construction in Developing Countries*. 14(1), 1-14.

Haron, Z., Mohd Noh, H., Yahya, K., Omar, W. and Abd Majid, Z. (2012). Assessing Noise Emission Levels from Earthwork Construction Equipment. *Malaysian Journal of Civil Engineering*. 24(1), 13-28.

Idris, N. (2012). *Automated Prediction of Noise from Construction Site Using Stochastic Approach*. Master Thesis. Universiti Teknologi Malaysia.

Jahya, Z. (2014). *Automated Construction Noise Prediction by Considering the Variability of Noise Sources and Outdoor Sound Propagation*. Master Thesis. UTM.

Li, X., Zhu, Y., and Zhang, Z. (2010). An LCA-based environmental impact assessment model for construction process. *Built and Environment, 45*, 766–775.

Manatakis, E., and Skarlatos, D. (2002). A statistical model for evaluation and prediction of the noise exposure in a construction equipment area. *Applied Acoustics, 63*, 759–773.

Muzet, A. (2007). Environmental noise, sleep and health. *Sleep Medicine Reviews, 11*, 135–142.