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ASSESSING NOISE EMISSION LEVELS FROM EARTHWORK CONSTRUCTION EQUIPMENT

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Abstract: Noise emission levels from construction equipment are an important factor in the determination of the level of noise exposure of construction workers and the neighbourhood. This paper presents: (1) an investigation of the noise emission levels generated from typical earthwork construction equipment, that is, excavators and compactors; (2) a comparison between the noise emission level obtained from local equipment and the noise emission level given by the United Kingdom standard BS5228:2009. Noise emission levels of 50 excavators and 25 compactors with various power levels and ages were obtained from on-site measurements. About 74% and 48% of the excavators measured in this study were shown to have noise emission levels below the limits specified by the Department of Environment (DOE) Malaysia and European Directive 2005/88/EC respectively, while 52% of compactors achieved levels below the EC limits. There is also a strong relationship between the mean sound pressure level and the age factor but an insignificant relationship with increases in net installed power. A comparison of measured data with BS5228 data indicated that statistically only new data in BS5228:2009 have insignificant differences from measured data. With these results new data in BS5228:2009 can be used with confidence by environmental impact assessment (EIA) practitioners during the prediction of noise at the planning stage.

Keywords: *noise emission level; earthwork construction equipments; sound power level; permissible noise limit; construction noise prediction*

1.0 Introduction

Excessive construction noise is detrimental to the environment. Construction activities, particularly earthworks involving site clearance, excavation, filling, cutting, and compaction, have high noise levels and are directly linked to the machinery used. According to Ballesteros *et al.* (2010), excavation is the noisiest stage, since it has great variability in the emitted levels as the high value of the sound climate reveals, mainly due to the large difference between the background noise of the machinery engines and the peak levels caused by the hoe loading. Most earthwork machines are fitted with powerful diesel engines (Budney *et al.*, 2009; Spessert & Kochanowski, 2010) and utilize robust transmission systems and others accessories for mobility (Vardhan *et al.*, 2006). For example, according to Fang *et al.* (2009), an excavator discharges a large amount of high level noise while working, comprising the inlet noise, exhaust noise, noise radiated from the machine body, and gear noise. However, among these the exhaust noise from the engine is one of the most important noises when the excavator is working. Nevertheless, the noise emission level depends on the age of the equipment (Vardhan *et al.*, 2006; Depczynski *et al.*, 2005), history of maintenance (Vardhan *et al.*, 2005, 2006), and mode of operation in either full working load or idle condition (BS, 1984, 1997, 2009).

The noise emissions level of construction equipment is a key factor in determining the noise exposure of construction workers. The noise exposure level of construction workers varies with the level of noise emissions of the equipment which they operate and other equipment used in their workplaces. Legris and Poulin (1998) reported that the average daily noise exposure among operators was 84 to 99 dB(A). A study by Fernandez *et al.* (2010), considering various stages of construction, which have different noise emission levels of equipment, showed that more than 60% of construction site workers have a daily exposure exceeding 80 dB(A), for which European Directive 2003/10/EC (EC, 2003) defines lower level actions which are required to provide protection. Over 55% of construction workers have exposure levels above 85 dB(A), where the use of hearing protection is compulsory, and 38% of workers experience more than 90 dB(A). Excessive noise exposure of construction workers can interfere with communication and cause hearing impairment (Schneider *et al.*, 1995; Sutter, 2002; Hong, 2005) and has been related with the occurrence of accidents (Bareto, 1997; Picard *et al.*, 2008). In order to avoid health hazards and accidents among construction workers some authorities suggest that the level of noise emissions of construction equipment used should fall below the permissible limit. The permissible limits are associated with net installed power (NIP); however there are differences in noise emission limits between the Malaysian DOE (DOE, 2004) and European Directive 2005/88/EC (EC, 2005). As an example, for an excavator, the former defines three categories: NIP of less than 70 kW has a limit of 106 dB(A), NIP of between 70 kw and 360 kW has a limit of 108 dB(A), and NIP greater than 360 kW has a limit of 118 dB(A). On the other hand European Directive 2005/88/EC (EC, 2005) defines two categories, whereby NIP of less than 55 kW should have a limit of 101 dB(A) and NIP greater than 55 kW is calculated using the formula 80 + 11 log NIP.

Accurate noise emissions levels are an important input for obtaining a reasonable prediction of noise level at the planning stage. The predicted noise level is acquired in the environmental impact assessment (EIA) study to rate the impact of construction activities before and during construction along with giving suggestions on how to reduce the impact. However, the proposed noise mitigation depends on the level of accuracy of prediction of noise emissions from sources that are expected to be used. For this reason, several studies have identified noise emission levels from sources on construction sites (Thalheimer, 2000; Waddington *et al.*, 2002; DEFRA, 2005; EC, 2000; BS, 1984, 1997, 2009; Dietrich *et al.*, 2008; Fernandez *et al.*, 2009; Schexnayder & Ernzen, 1999). In the USA, extensive measurements of construction plants' noise emission levels taken in conjunction with the Central Artery/Tunnel (CA/T) Project by Thalheimer (2000) were used by the Federal Highway Administration (FHWA) as a database for prediction of the highway construction noise of its Road Construction Noise Model (RCNM).

Meanwhile in the UK, recent sound level measurements of construction equipment and activities conducted by the Department of Environment, Food and Rural Affairs, UK (DEFRA, 2005) are found in the new version of BS5228 (BS, 2009). In some studies, such as those by Jafferson (1997) and Waddington *et al.* (2000), it was found that data in a previous version of BS5228 (BS, 1984) exceeded the values measured at the actual location and thus led to a noise level that is expected to be conservative. On the other hand, it was found that emission data in BS5228:1997 (BS, 1997) can be used with the same confidence as the measured data (Waddington *et al.*, 2000). Moreover, Gilchrist, Allouche, and Cowan (2003) reported that there are some differences between predicted and actual noise from sites that have the same characteristics because data for factors such as equipment are more conservative than the actual output of the equipment on site. In Malaysia, the DOE recommends that BSS5228:1984 (BS, 1984) be used to estimate the level of noise even though the standard has been updated to the new version, BS5228:2009 (BS, 2009). Thus, the primary objectives of this investigation are: (1) to assess the noise emission level generated by excavators and compactors, which are the typical earthwork construction equipment; (2) to compare the measured data and noise emission data in BS5228 in order to determine whether there are any significance differences between them.

2.0 Materials and Method

2.1 Noise Level Measurement

The noise emission levels of 50 excavators and 25 compactors with various power levels and equipment ages that were utilized in this project were measured by a sound level meter. All measurements of noise emissions were made using a Type 2 Pulsar Model 64 data logging sound level meter which was calibrated using a sound level calibrator having a calibration frequency of 1000 Hz and a sound pressure level of 93.8 dB for a 1/2 diameter microphone. Excavators and compactors were selected because of the prevalence of their use among the earthwork equipment on site. The measurements were taken while each excavator and compactor was carrying out operations in each location spread across several construction projects in South Johor, Malaysia. During the measurements, proximity to other equipment, to roads, and to building facades was avoided. All measurements were carried out under ideal meteorological conditions: no wind and no rain. Details of equipment such as NIP, model, and age of excavator were recorded. Almost all machines have improper maintenance records and thus we ignored the maintenance history record. The noise measurements were carried out at six points 1 m from equipment as recommended in BS ISO 6393:2008 (BS, 2008) for 30 seconds at each point. Background noise level was measured when the equipment was off (Figure 1). Corrections were made if the difference between measured noise level and background noise level was less than 10 dB. Measurements obtained from six points were averaged to find a single noise emission level value $L_{Aeq,30s}$. The measured noise emission levels are compared with the maximum noise emission levels allowed by the DOE and EC limits. The relationships between noise emission level and age and between noise emission level and NIP were determined.

Figure 1: Measurement of background noise level when equipment (compactor) was off

2.2 Comparison with BS5228:2009

One problem during prediction of noise at the planning stage is that details of the equipment to be used are unavailable. The only available information is the architectural design (for buildings) or general layout (for open sites, e.g. landfill) and the plants are normally unknown. This comparison aims to determine whether the noise emission levels of excavators and compactors available in BS5228:2009 can be used as inputs to construction noise prediction models with equal confidence. In this paper noise emission data in BS5228 were classified into two categories: historical data that can also be found in the older versions, BS5228:1984 and BS5228:1997, and new data obtained from recent measurements of equipment used on actual construction sites in the UK by DEFRA. In comparing these data, measured noise emission levels were normalized to 10 m from the equipment's so-called sound pressure level.

Comparison using statistical analysis was performed to determine whether measured equipment and BS5228:2009 data can be used with the same confidence as inputs in the prediction of noise if the following are used: (i) mean sound pressure level for all measured excavators as well as all measured compactors; (ii) mean sound pressure level for specific excavators' and compactors' NIP. The first comparison is useful when details of the equipment are unknown and the second is helpful if the NIP is known during prediction.

3.0 Results and Discussion

3.1 Noise Emission Level Data

Figure 2 presents the measured noise emission level ($L_{Aeq,30s}$) values for all 50 excavators and 25 compactors, the allowable limits of DOE Malaysia for the maximum noise emission level of an excavator, and the allowable limits of the EC for both excavators and compactors. The allowable limit for a compactor was not available from DOE. We can see that only 13 excavators, representing 26% of the total number of excavators considered in the survey, had noise emission levels (L_{Aeq}, 30 seconds) with a maximum value of 116 dB(A), meaning that the rest of them were in accordance with the DOE legislation (DOE, 2004). This is in agreement with the observation of Ballesteros *et al.* (2010) that excavation is the noisiest stage. In comparison with the EC limit, however, 52% of the total number of excavators and 48% of compactors exceeded the more stringent noise emission level limits permitted by European Directive 2005/88/EC (EC, 2005). EC limits concern the risk of health hazards to workers, and thus the results implied that there is a possibility that operators may be exposed to such risks as well as to risk of accidents during the course of their work.

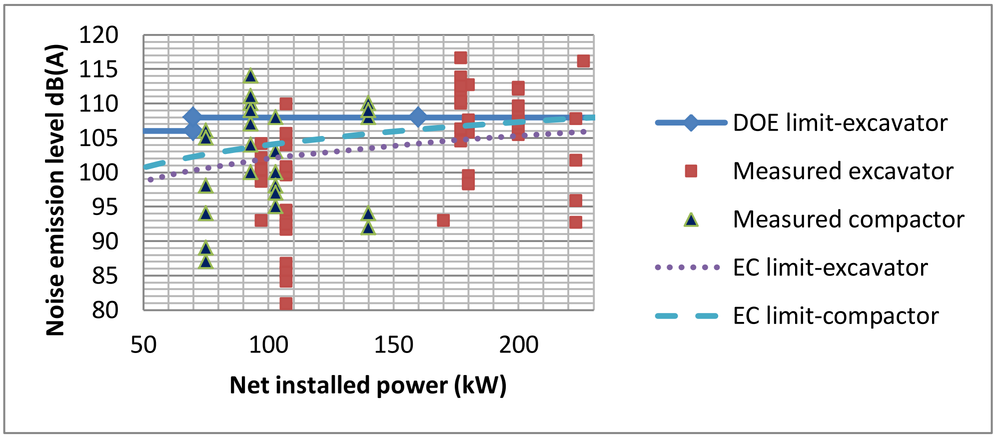
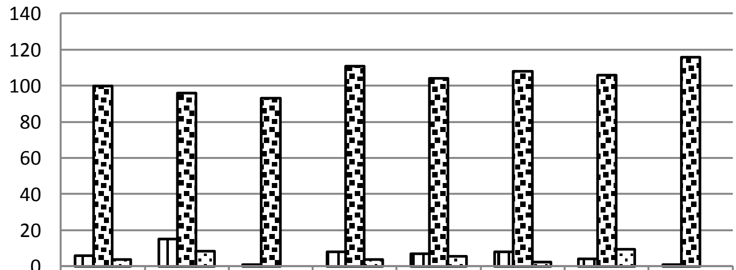


Figure 2: Noise emission levels from measured equipment

3.1.1 Relationship Between Noise Emission Level and NIP

The excavators and compactors were categorized under the specific NIP, and descriptive statistics including number of samples, specific mean noise emission level, and standard deviation are shown in Figures 3 and 4, respectively. It is revealed in Figure 4 that the largest number of uses of excavators (about 30%) involved excavators with NIP of 107 kW. It is seen that the mean noise emission level for each excavator's and compactor's NIP does not have a special relationship with the increase in NIP. Some excavators with low NIP produce significantly higher emission levels than those with higher NIP and vice versa. This was also reported by Waddington *et al.* (2000). Fifty percent of the variability in noise emission level is related to NIP (multiple R = 0.707, R^2 = 0.50) while only 13% of the variability in noise emission levels of compactors is related to NIP (R = 0.129 and R^2 = 0.017). A one-way ANOVA also showed there are significant differences between mean emission levels for each NIP with F(5,42) = 9.2 and p = 0.0001. The averages of all mean noise emission levels of excavators and compactors were 103 dB(A) (standard deviation = 7.91) and 102 dB(A) (standard deviation = 7.46), respectively.



	97kW	107kW	170kW	177kW	180kW	200kW	223kW	226kW
Number of samples	6	15	1	8	7	8	4	1
Mean noise emission levels	100	96	93	111	104	108	106	116
Standard deviation	3.78	8.53	0	3.91	5.57	2.55	9.31	0

Figure 3: Statistical description of excavators based on specific NIP

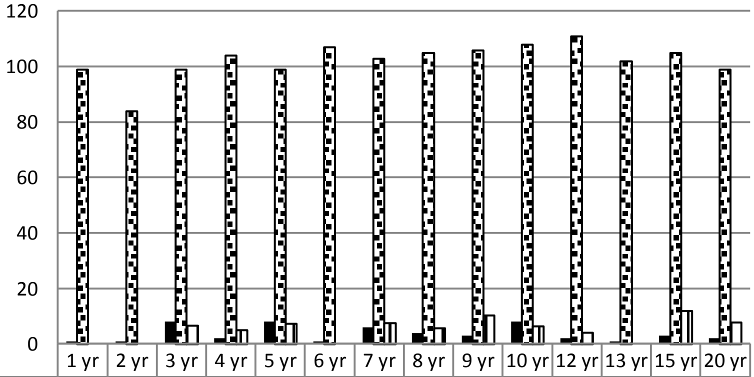
	75kW	93kW	103kW	140kW
Number of samples	6	7	6	6
Mean noise emission levels	97	108	100	101
Standard deviation	7.96	4.67	4.7	8.99

Figure 4: Statistical description of compactors based on specific NIP

3.1.2 Relationship Between The Noise Emission Level and Age of Equipment

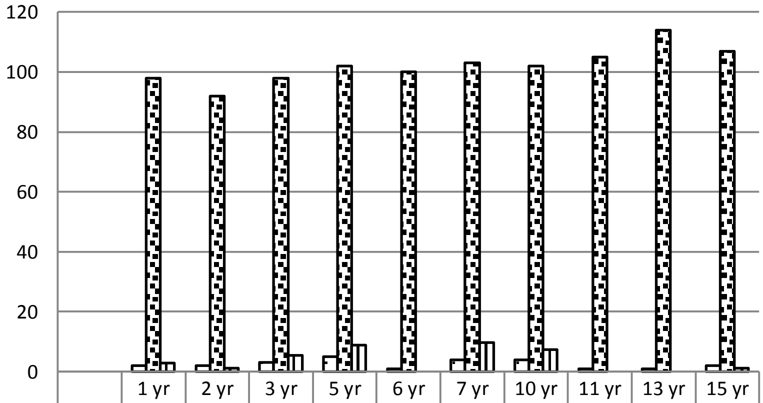
With regard to the age of the measured excavators and compactors, the descriptive statistics including number of samples, specific mean noise emission level, and standard deviation are shown in Figures 5 and 6, respectively. Twenty-eight percent of them were less than 5 years old when considering both excavators and compactors, while 60% of excavators and 56% of compactors were between 5 and 10 years old. Twelve percent of excavators and 16% of compactors were more than 10 years old. The lowest age of both excavators and compactors in use was 1 year while the oldest excavators and compactors were 20 years and 15 years old, respectively. For all excavators, only 13% of variability in noise emission level is related to the age factor (multiple R = 0.301, R^2= 0.130). The same condition was obtained for the data of the measured compactors.

Interestingly it was found that there are very good to good linear relationships between the noise emission level of each NIP and the age of excavators and compactors (Figures 7 and 8). Table 1 shows that all equipment with specified NIP has a multiple R greater than 0.7 except for the excavator with NIP of 97 kW (R2 = 0.016) and the compactor with NIP of 140 kW (R2 = 0.2315). Thus, in general it is indicated that the relationship between the noise emission level and the age of equipment with a specific NIP is that the older the equipment, the higher the noise emission level. This relationship has been shown consistently elsewhere (Vardhan et al., 2005; Vardhan & Raj, 2008) and is considered indisputable. Although all items of equipment in this research lacked maintenance histories, according to previous research by Vardhan (2006) the same reason could be applied here for the high noise levels of the older equipment.



	1 yr	2 yr	3 yr	4 yr	5 yr	6 yr	7 yr	8 yr	9 yr	10 yr	12 yr	13 yr	15 yr	20 yr
Number of samples	1	1	8	2	8	1	6	4	3	8	2	1	3	2
Mean noise emission levels	99	84	99	104	99	107	103	105	106	108	111	102	105	99
Standard deviation	0	0	6.65	4.95	7.42	0	7.69	5.74	10.39	6.53	4.24	0	12.01	7.78

Figure 5: Statistical description of excavators based on age factor



	1 yr	2 yr	3 yr	5 yr	6 yr	7 yr	10 yr	11 yr	13 yr	15 yr
Number of samples	2	2	3	5	1	4	4	1	1	2
Mean noise emission levels	98	92	98	102	100	103	102	105	114	107
Std. Deviation	2.93	1.14	5.42	8.93	0	9.77	7.26	0	0	1.19

Figure 6: Statistical description of compactors based on age factor

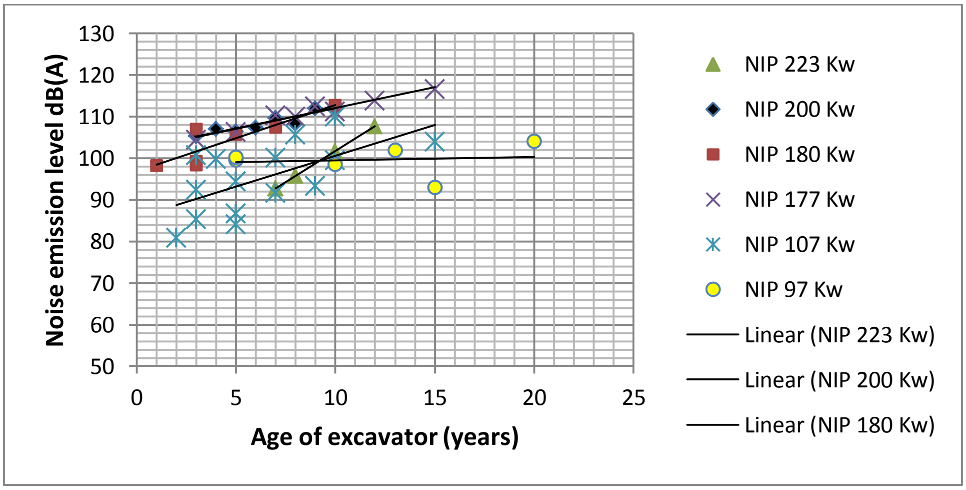


Figure 7: Relationship between excavator age and noise emission level for a variety of NIP

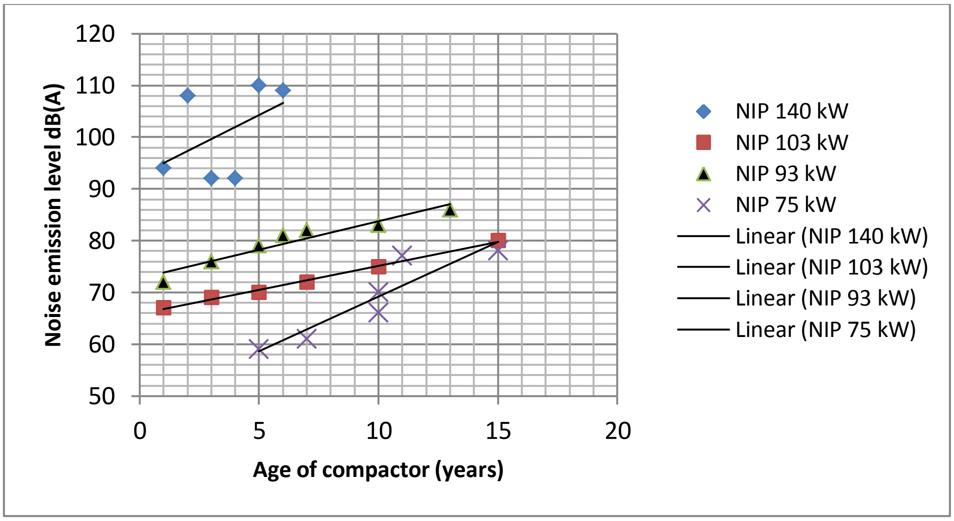


Figure 8: Relationship between compactor age and noise emission level for a variety of NIP

Table 1: Relationship between noise emission level and age for specific NIP

NIP	Number of samples	Noise emission levels, dB(A)	Standard deviation	R^2
Excavators: 97 kW	6	100	3.78	0.016
107 kW	15	95	8.53	0.505
177 kW	8	111	3.91	0.963
180 kW	7	104	5.57	0.742
200 kW	8	109	2.55	0.822
223 kW	6	101	9.31	0.955
Compactors: 75 kW	6	97	7.96	0.812
93 kW	7	108	4.67	0.885
103 kW	6	100	4.70	0.991
140 kW	6	101	8.99	0.232

3.2 Comparison with BS5228 data

3.2.1 Mean Sound Pressure Level of Each Type of Plant

Comparisons between new, historical, and measured data are presented visually in Figures 9 to 11 for excavators and in Figures 12 to 14 for compactors. Regarding excavators, it was found that the measured excavators have NIP greater than 80 kW while historical data are less than NIP 80 kW. Observing Figures 10 and 11, it can be seen that new data in BS5228:2009 have similar NIP to the measured equipment. In contrast with the excavators, it was found that the measured compactors have a range of NIP similar to that given by both historical data and new data. Table 2 shows the results of a two-tailed *t*-test carried out to compare the mean sound pressure level of measured compactors and excavators ith BS5228 data (BS, 2009). Established suitable null and alternative hypotheses were used: null hypothesis H_0: $\mu = \mu_0$ and alternate hypothesis H_A: $\mu \neq \mu_0$, where μ_0 is the mean sound pressure level given in BS5228 (BS, 2009) for each type of equipment and μ is the sample mean of the measured equipment. For the condition $p < \alpha = 0.05$, the null hypotheses are rejected. There are significant differences between mean sound pressure levels of historical data and measured data for excavators and compactors since $p < 0.05$. In other words, the critical value of t for the two-tailed test is much smaller than the t value and this indicates that it can be stated with 95% certainly that there really is a difference between the data of the two samples. The results of the dependent *t*-test for new data show that $p \geq 0.05$. Consequently, the null hypothesis that there is no significant difference between the mean sound pressure level of measured and new data is accepted, indicating with a 95% confidence level that there really is no difference between the two samples' data.

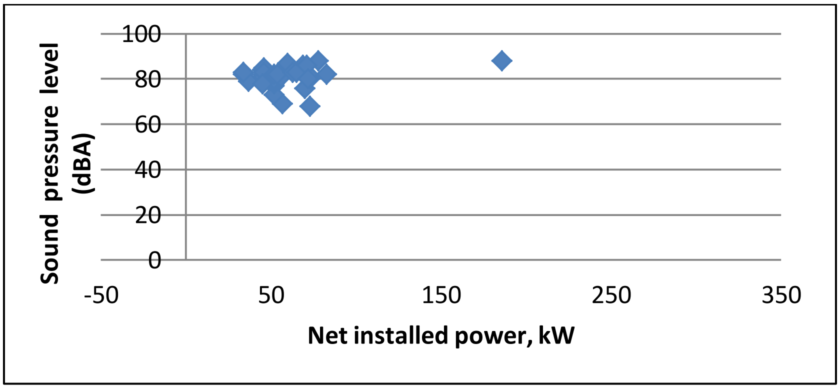


Figure 9: Historical data for excavators contained in BS5228:2009 (mean = 80 dB(A))

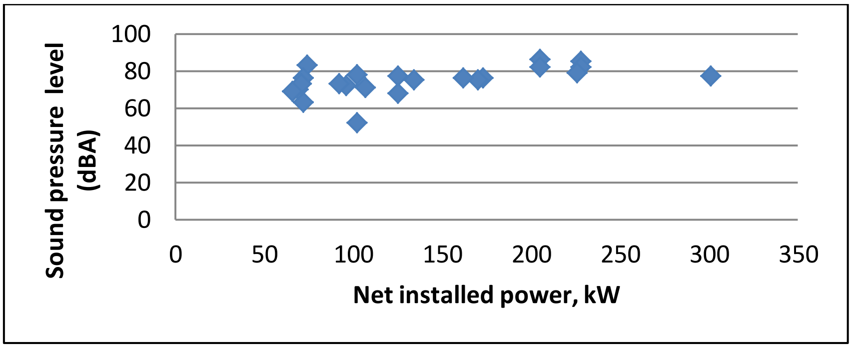


Figure 10: New data for excavators contained in BS5228:2009 (mean = 72 dB(A))

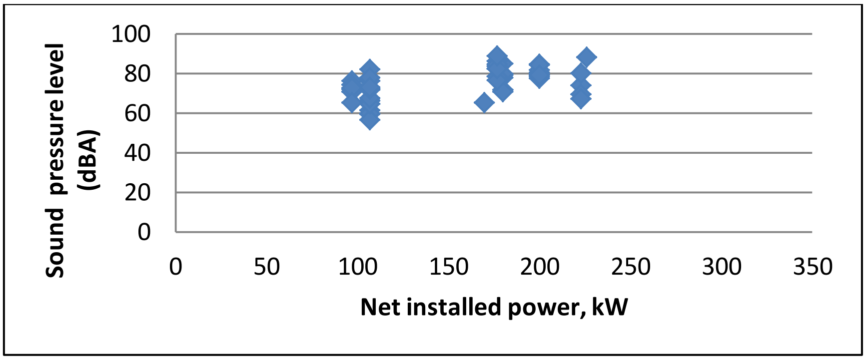


Figure 11: Sound pressure level for measured excavators (mean = 75 dB(A))

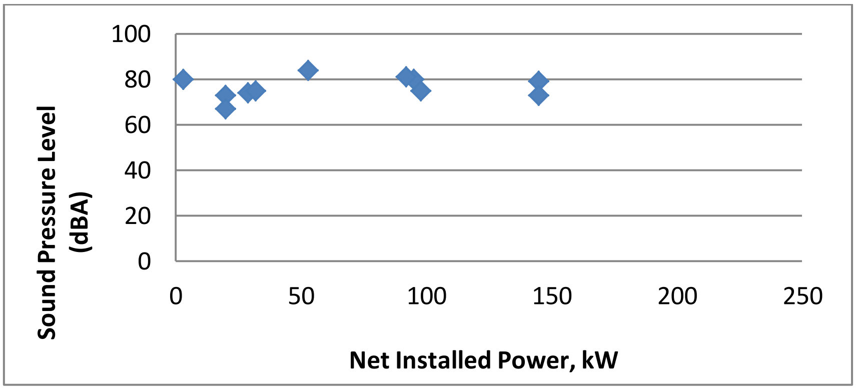


Figure 12: Historical data for compactors contained in BS5228:2009 (mean = 79 dB(A))

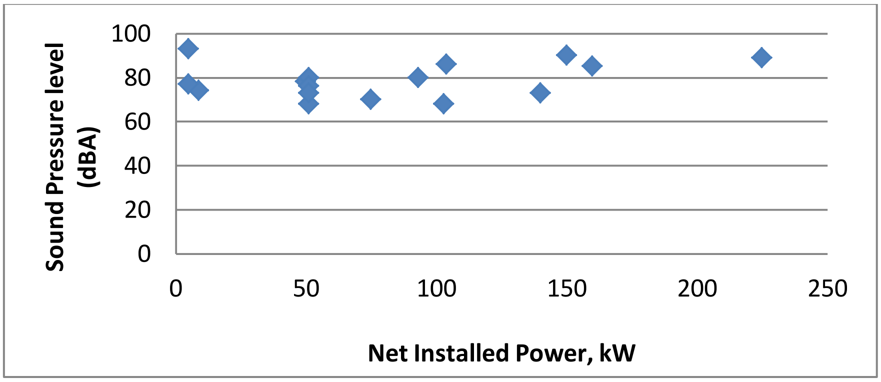


Figure 13: New data for compactors contained in BS5228:2009 (mean = 77dB(A))

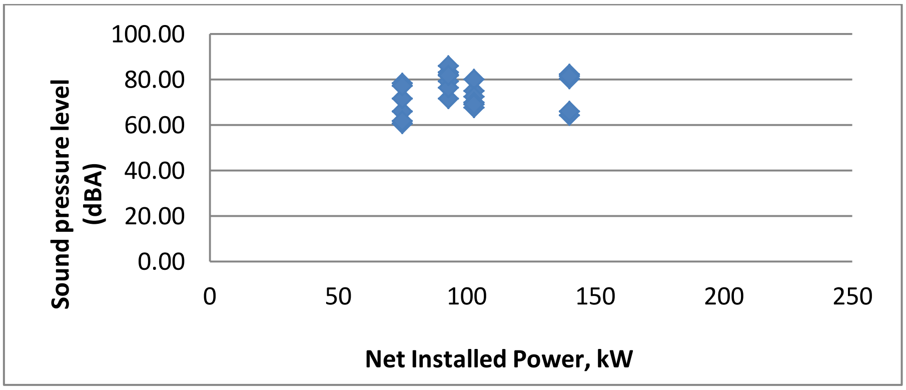


Figure 14: Measured data for compactors (mean = 74 dB(A))

Table 2: Summary of *t*-test results for the measured data, historical data, and new data from BS5228-1:2009

Equipment	Mean sound pressure level, 10 m			Measured data vs. historical data from BS5228-1:2009		Measured data vs. new data from BS5228-1:2009	
	Historical data	New data	Measured	*p*	*t*-stat.	*p*	*t*-stat.
Excavator	80 N = 42	75 N = 21	75 N = 50	0.001	4.66	0.16	1.42
Compactor	79 N = 11	74 N = 15	74 N = 25	0.03	2.27	0.06	1.98

3.2.2 Mean Sound Pressure Level for Specific NIP

It has been found statistically that the mean sound pressure levels for measured data and the mean sound pressure levels for new data have insignificant differences and both can be used with equal confidence. It was found that the measured data and UK historical data have different NIP and thus cannot be compared. Table 3 shows the comparison of mean sound pressure level for the same NIP between measured data and new data from BS5228:2009. It is indicated that excavators with NIP of 177 kW and 180 kW have higher measured average sound levels than data from BS5228:2009 (BS, 2009), with differences of 2 dB(A) and 1 dB(A), respectively, as shown in Table 3. Meanwhile NIP of 223 kW, 200 kW, and 97 kW have lower measured average sound pressure levels compared to the data of BS5228 (BS, 2009), with differences of 4 dB(A), 6 dB(A), and 3 dB(A), respectively. The significant difference between these two mean sound pressure levels was examined by a *t*-test using established suitable null and alternative hypotheses: null hypothesis H_0: $\mu = \mu_0$ and alternate hypothesis H_A: $\mu \neq \mu_0$, where μ_0 is the mean sound pressure level in BS5228 (BS, 2009) for each NIP and μ is the sample mean of the measured data for each NIP. For the condition $p < 0.05$ the null hypotheses are rejected. The results showed that only the mean sound pressure level for the excavator with a specific NIP of 200 kW was significantly lower than the data in BS5228 (BS, 2009) with $t(7) = |\ 6.014\ |$, $p = 0.001$, and $\alpha = 0.05$.

Table 3: Summary of *t*-test results for the specific NIP between measured data and new data from BS5228-1:2009

Net installed power	N	Mean Sound pressure level (measured) dB(A)	Std deviation dB(A)	Mean sound pressure level (new data in BS5228:2009)	*t* statistic	df	*p* (two-tailed)
Excavators: 97 kW	6	72	3.78	72	–.225	5	.831
107 kW	15	67	8.53	71	–1.690	14	.113
177 kW	8	83	3.91	81	1.214	7	.264
180 kW	7	76	5.57	75	.565	6	.592
200 kW	8	81	2.55	86	–6.014	7	.001
223 kW	6	73	9.31	77	–.998	5	.364
Compactors: 75 kW	6	69	7.96	70	–.461	5	.664
93 kW	7	80	4.67	82	–1.214	6	.270
103 kW	6	72	4.70	68	2.168	5	.082
140 kW	6	73	8.99	73	–.045	5	.966

4.0 Conclusions

The noise emission levels of 50 excavators and 25 compactors with various power levels and ages were obtained from on-site measurements of several construction projects in Universiti Teknologi Malaysia, Skudai Campus, Malaysia. About 74% and 48% of the excavators measured in this study were shown to have noise emission levels below the limits specified by DOE Malaysia (DOE, 2004) and European Directive 2005/88/EC (EC, 2005), respectively, while 52% of compactors achieved levels below the EC limits. There is also a strong relationship between the mean sound pressure level and the age factor but an insignificant relationship with increases in net installed power. Statistically it was found that only new data in BS5228:2009 have insignificant differences from measured data. In conclusion, new data in BS5228:2009 can be used with confidence during the prediction of noise at the planning stage and are able to give more confidence to the environmental impact assessment (EIA) practitioner in prescribing specific measures to eliminate or minimize the adverse impacts of development projects.

Acknowledgements

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