University of Salford
A Greater Manchester University

HUMAN RESPONSE TO VIBRATION IN RESIDENTIAL ENVIRONMENTS (NANR209)

TECHNICAL REPORT 4

CALCULATION OF NOISE EXPOSURE

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FOREWORD

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PREFACE

This document is one component of the Defra project NANR209 'Human response to vibration in residential environments' final report.

The NANR209 Final Report consists of the following documents:

- Executive summary
- Final project report
- Technical report 1: Measurement of vibration exposure
- Technical report 2: Measurement of response
- Technical report 3: Calculation of vibration exposure
- Technical report 4: Measurement and calculation of noise exposure
- Technical report 5: Analysis of the social survey findings
- Technical report 6: Determination of exposure-response relationships

The project was performed at the University of Salford between January 2008 and March 2011. During that time the following University of Salford researchers worked on the project. David Waddington, Andy Moorhouse, Mags Adams, Geoff Kerry, Rodolfo Venegas, Andy Elliott, Victoria Henshaw, Eulalia Peris, Phil Brown, Andy Steele, Jenna Condie, Gennaro Sica, James Woodcock, Deborah Atkin, Nathan Whittle, Zbigniew Koziel, George Perkins, Natalia Szczepanczyk, Sharron Henning, Ryan Woolrych, Heather Dawes, Amy Martin, Maria Beatrice Aquino-Petkos, Laura Jane Buckley, Catherine McGee, Andrew Caunce, Valentin Le Bescond, Stephanie Jones, Dawn Smail, Andrew King, Lauren Hunt, Michael Gerard Smith, Tomos Evans.

The work by the University of Salford benefited from guidance by the Defra project steering group. The Defra project steering group consisted of Richard Perkins and Colin Grimwood on behalf of Defra, Colin Stanworth representing the interests of the British Standards Institution working group for BS6472, Rupert Thornely-Taylor representing the interests of the Association of Noise Consultants, and Henk Miedema, Sabine Janssen and Henk Vos from TNO (Netherlands Organization for Applied Scientific Research).

This project benefited from guidance in the design of the vibration measurement equipment from the suppliers Guralp Ltd.

The peer review of the railway questionnaire was performed by Jim Fields, Larry Finegold, Evy Öhrström, Peter Brooker, and Gary J Raw.

This research would not have been possible without the kind cooperation of the residents that took part in the field trials.

The work presented is research performed by the University of Salford funded by Defra.

EXECUTIVE SUMMARY

Although vibration is the primary focus of the "*Human response to vibration in residential environments*" project, it can be seen in the literature that noise, which covariates very well with vibration, can facilitate annoyance. Work was done towards analysis of vibration exposure and noise exposure separately, as was analysis of the combined effect from both. In the report *Human response to vibration in residential environments*, an analysis of combined effects from noise and vibration is performed.

The objectives of this technical report were to obtain internal and external exposure to noise in residential environments for three separate sources; railway traffic, construction work and internal sources. As such, exposures were obtained in two steps. In the phase one, external measurements and estimation were performed in the absence of internal measurements. In the phase two, exposures over 24h were calculated for railway traffic. Additionally, owing to the nature of construction occurring during the daytime period, only daytime (rather than 24h) exposure from those sources was calculated.

Exposure to noise from railway traffic was obtained from calculation of L_{den} based on the Calculation of Railway Noise guidelines (Department of Transport, 1995)[1]. This noise descriptor was used for the assessment of railway noise as residents are exposed over a 24h period. On the other hand, for a determination of exposure to noise from construction activities a noise descriptor such as $L_{Aeq,0700-1900}$ seems to be adequate as only daytime activities were observed and recorded during measurements. Details of determining the exposures are explained further in this report.

Calculation was performed for all residents for whom vibration exposure was measured. Predictive procedures were chosen due to the absence of a significant number of external measurements. This is a well known standardised routine, although it requires many details regarding train type, the number of vehicles that a train is composed of and noise emission from a particular vehicle. All details about trains were obtained from sources below:

- Control positions used for the monitoring of vibration from railway traffic for 24h
- Timetables obtained from the National Rail Enquiries website
- Freightmaster - a guide to rail-borne freight services in the country (Freightmaster, 2011)
- Two Line Speed Profile reports from 2005 and 2009 (Goffey, 2005; Moor, 2009)

Exposure from construction work was calculated from measurements. Some activities were unable to be captured successfully. Such problems were encountered mostly due to an

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[1] Calculation of Railway Noise Department of Transport, 1995 is also denoted as CRN in this report

inability to anticipate the schedule of construction work as well as frequent changes to any pre-existing schedule. Consequently, an estimation of these construction activities was provided instead.

A significant number of limitations was encountered during internal measurements of noise from railway sources. As explained in detail in Section 3.2, the primary noise source of interest was often easily masked by extraneous internal sources. Consequently, poor results of many events or no events were obtained at all. External measurements however yielded clear, comprehensive and distinct events, identifiable over background noise.

Secondly, a number of problems during measurements of construction sources were encountered. One of the main problems relates to the very strong influence of background noise. As a result, noise measurement was significantly contaminated, particularly by road traffic. Activities such as saw-cutting, excavation, flattening, etc. that occurred in the East Manchester site have greater uncertainties associated with obtained results. On the other hand, the South of Manchester site was situated at an increased distance from road traffic and thus fewer uncertainties were expected for the construction activities identified.

Another problem, addressed above for rail noise, is that encountered when performing internal measurements. As such, only external measurements were performed. However, an internal exposure was estimated from an external exposure. There is a good correlation between external and internal exposure.

CONTENTS

LIST OF FIGURES

1 Introduction

The Defra funded project "*Human response to vibration in residential environments*" started in April 2008, the aims of which refer to the relationship between exposure and response. The term "exposure" relates to single or combined effects from vibration and noise. However, emphasis was mainly placed upon calculation of exposure to vibration. The description of determination of exposure is described in Technical Report 3 "*Calculation of Vibration Exposure*" 3 (Sica et al., 2011). Evaluation of associated noise was performed as part of the project, since analysis of the resulting annoyance responses would prove valuable when considering the results arising from combined effects.

The following sections present methodologies for the measurement and calculation of environmental noise arising from railway traffic and construction work. Chapter 3 provides information regarding the calculation of railway noise exposure using CRN (Department of Transport, 1995). The chapter also describes assumptions made and recorded observations in the implementation of this routine. It additionally presents results, analysis and conclusions with a presentation of final exposures for all residents.

Chapter 4 provides a description of the methodology for finding exposure to noise from construction sources. Noise exposures for these sources are primarily determined from results based on measurements performed according to BS 5228-1:2009. Calculated exposures to noise for all residents are presented with detailed analysis and conclusions. Owing to difficulties involved in anticipating the construction schedule, a number of activities could not be directly measured. A prediction of their noise emission is therefore provided instead.

The report also details the reasons for which calculations were preferred over measurements pertaining to both railway traffic and construction work.

1.1 Review of preceding work

Noise measurements were conducted according the procedures which can be found in APPENDIX A and B. The integrating Class 1 sound level meter (01dB SIP95) was set up on the pavement 1m away from the façade of a property most exposed to noise from construction activities and 1.5 m above level ground.

The preceding work mostly covers a methodology for the noise measurement of construction work, particularly measurements of noise from piling. In terms of the construction work, the techniques involve an estimation of noise exposure at the most exposed external wall of a dwelling using methods described in BS 5228-1:2009. A calculated noise exposure was determined from on-site measurements of sound pressure level of activities and an identification of activities from long term vibration monitoring. Results were derived from the South Manchester site where a new tram line was in the process of construction.

Ideally, an exposure-response analysis would encompass a 24-hour period, separated into daytime, evening and night-time hours. Construction sites are generally active during daytime hours only, but some also operate during evening and/or night-time hours. The minimum detail required are L_{Aeq} levels: one for daytime, one for evening and one for night-time period between 7am and 7pm, 7pm and 11pm and 11pm and 7am respectively[2]. However, as construction only occurred during the daytime period, a daytime exposure is considered for analysis purposes. Spectra and other A-weighted noise indices including L_{Apeak}, L_{A90} and L_{A10} were also considered as required in the report.

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[2] The hours are coded as 0700, 1900 and 2300 corresponding to 7am, 7pm and 11pm respectively

2 Literature review

2.1 Prediction of noise exposure from railway sources

Calculation of Railway Noise (Department of Transport, 1995) describes the procedure of estimating noise arising from railway traffic sources. Although published 16 years ago, this document is still widely considered as providing the best predictive method of assessing railway noise, despite the fact that new trains have entered operation in the intervening period. Additional Railway Noise Source Terms For "Calculation of Railway Noise 1995" (Department of Transport, 2007) provides some complementary information pertaining to noise emission.

The accuracy of estimation procedures may suffer due to a number of errors (Hepworth, 2006). Main points identified are errors in calculation methodologies, implementation of methodologies, errors in input data, errors introduced in processing data for noise mapping, errors introduced in the software calculation of noise levels – efficiency techniques. The term noise mapping is used in the sense that noise emissions from vehicles would be calculated for every residence covered by an area of noise pollution. Errors introduced may be evaluated as a calculation of uncertainty (Craven & Kerry, 2001).

2.2 Calculation of noise exposure from construction sources

A number of British Standards consider the calculation of exposure to noise from construction sources by evaluating the sound power level of a source. BS EN ISO 3740:2001 provides with basic guidance for the determination of the sound power level of a noise source.

The methodology for obtaining noise exposure is also covered by the Code of Practice for Noise on Construction and Open Sites BS 5228-1:2009, which deals with situations such as stationary and mobile plants within closed areas or moving along a defined route. The standard contains an extensive number of values for sound power level of corresponding plants, which provides an opportunity to predict sound emission from machinery for which measurement results could not be obtained.

In the project, emphasis was placed upon investigation of external and internal exposures. Shield (Shield & Dockrell, 2004) discusses problems of internal exposure to environmental noise inside classrooms at schools. Insufficient data was found to assess whether a good correlation existed between external noise and internal exposure. Similarly, internal exposure from transportation noise was investigated by Graham (Graham et al., 2009), although a different methodology was applied. A single external monitor and up to twelve internal monitors were installed depending on a number of participants. The difference between external and internal levels was then calculated using a selection of 100 of the loudest and quietest individual noise events subjected to the least contamination from internal noise sources. The results indicate a good relation between indoor and outdoor exposures (Graham et al., 2009). Two British Standards BS 8233:1987 and BS EN 12354-3:2000 provide with methodology of estimation internal exposure based on an external measurement. BS 8233:1987 provides with an estimation of the attenuation provided building envelope whereas BS EN 12354-3:2000 describes the calculation of sound insulation or sound pressure level difference of a façade of other external surface of a building.

The European Union's Environmental Noise Directive (Directive 2002/49/EC, 2002) states that a common noise indicator for assessing annoyance is L_{den}[3] (sometimes denoted as DENL), and sleep disturbance may be assessed using the L_{night}[3] metric. It is also useful to provide supplementary indicators in order to monitor or control more sophisticated situations during noise exposure. It became a common approach in research that exposure to noise in relation to annoyance response is determined by either L_{dn}[3] (sometimes denoted as DNL) or L_{den}. Researchers such as Shultz (Schultz, 1978) and Fields (Fields & Walker, 1982) use L_{dn} as a noise exposure measure and percentage highly annoyed (%HA) as a noise annoyance measure. Following this approach, other researchers also referred to the L_{dn} noise descriptor to express noise exposure (Fields, 1994; Miedema & Vos, 1998). Miedema & Oudshoorn (2001) later used L_{den} as a noise measurement descriptor, which includes the evening as a distinct and separate period of the day. According to suggestions from EU Directive (Directive 2002/49/EC, 2002) and research presented by other papers, L_{den} appears to be the most appropriate noise measurement metric for railway sources. However, the main construction work took place within the daytime (usually between 7:00 and 19:00), and thus L_{day} may be considered sufficient for expressing the noise exposure from construction sources.

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[3] The day-evening-night level L_{den} (in dB) describes the overall 24h noise exposure giving extra penalties for evening-time (+5dB) (L_{evening}) and night-time (+10 dB) (L_{night}) . Full definition can be found in The European Union's Environmental Noise Directive in Annex I (Directive 2002/49/EC, 2002).

L_{dn} is defined similarly to L_{den} but L_{evening} is not included in calculation of overall noise exposure; although estimation of noise exposure from railway according to CRN (Department of Transport, 1995) is expressed in L_{dn}, calculation was done to obtain noise exposures in terms of L_{den}

3 Determination of noise exposure for Railway Sources

3.1 Introduction

The process of determining exposure to noise from railway traffic was begun later than the determination of exposure to vibration. Most sites had already been covered by the technical team. These issues influenced the decision to determine the noise exposure from prediction.

For the other sites at which noise measurements could be conducted, noise emission from a single train occurrence was measured. The great majority of measurements were of passenger trains, but measurements of freight trains were also obtained from locations where this was possible. This data was intended to be used as a validation for the prediction process. The measurements themselves were conducted according to BS 7445-2:1991, CRN (Department of Transport, 1995) additionally specifies a number of conditions which must be followed if such results are to be used in prediction.

For predictive purposes, information about a number of passenger and freight trains was obtained from accelerometers which monitored vibration for 24h. A simple algorithm for separation of freight and passenger trains was used according to assumptions specified in Section 3.2. Noise emission from a single vehicle was ascertained from the relevant table in CRN which provides values of sound exposure level L_{AE} for different train types. This is the hypothetical sound pressure level which if sustained for one second would contain the same energy as an actual noise event, regardless of duration;

$$L_{AE} = 10\log_{10}\left(\sqrt{\frac{1}{1s}\int_0^T p_A{}^2(t)dt} \,/\, p_0\right) \quad \textbf{Equation 1}^{4}$$

Consequently overall exposure from railway traffic was calculated following CRN methodology.

3.2 Noise measurement overview for railway sources

3.2.1 Measurements

Noise exposure from railway traffic was predicted from CRN but a number of measurements were conducted according to the procedure defined in Appendix A. Due to the objectives of this project including a determination of an internal exposure, a number of indoor measurements were also performed according to Appendix B. Unfortunately, the recordings from internal measurements did not provide adequate results. Internal noise due to external

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[4] Sound Exposure Level (abbreviated as L_{AE} or SEL) applies to discrete noise events and is defined as the constant level that, if maintained during 1 s interval, would deliver the same A-weighted sound energy to the receiver as the real-time varying event. It can be also understood as a $L_{Aeq,T}$ normalized for T = 1 s (Crocker, 2007)

sources was found to be of insufficient level so as to allow the identification of noise events, and contamination of noise from these external sources occurred through masking by events within the dwelling itself, e.g. resident conversations, television etc.

Only a limited number of outdoor measurements were conducted for railway noise sources. The reason for this lies behind the fact that both noise and vibration measurements were to occur simultaneously in terms of combined effects on annoyance. Technically, only couple of noise measurements could be carried out during much greater number of simultaneous vibration measurements. Additionally, the process of an overall noise and vibration measurement to take place required to schedule time and date according to participants' time available. Unfortunately, these technical problems caused difficulties in obtaining a greater number of results.

All measurements of noise from railway traffic were conducted according to the procedure described in Appendix A. It specifies the position of a sound level meter in an outdoor measurement such that the instrument is placed at a distance of 1m from the most exposed facade and at a height of 1.5m above ground level. In terms of period, all noise measurements were carried for as long as vibration measurements, which according to the procedure have been specified to be 30 min as minimum. This period, however, varied due to number of circumstances on site, along with the number of events recorded was the most important. For the prediction, results obtained from measurements are used. Despite the conditions specified in CRN (Department of Transport, 1995), for logistical reasons only a selected number of measurements were performed. Additionally, difficulties were encountered in placing the monitoring equipment in a position free from the influence of obstacles within a 50m radius.

3.2.2 Results

This section covers all the results obtained from measurements only. Figure 1 and Figure 2 illustrate examples of internal measurements. Figure 1 is an example of a very noisy event occurring during a measurement period. The time varying value of $L_{\mathrm{Aeq,1s}}$ in this case (exceeding 65 dB(A)) suggests possible construction work.

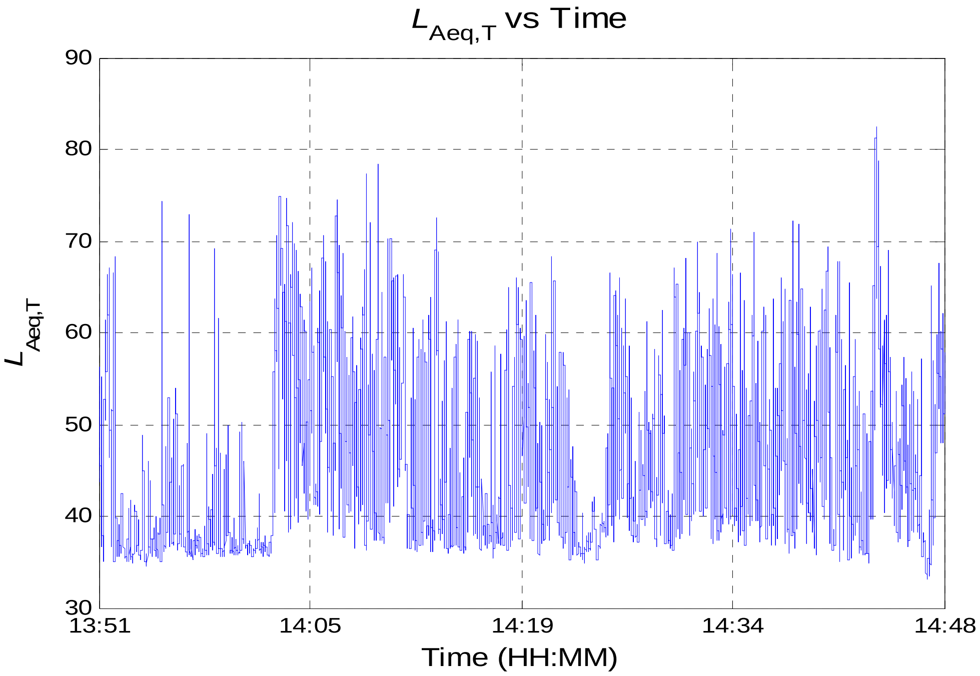

Figure 1 presents an internal noise measurement of a train taken in Birmingham on the 26th January 2010. The residence was subjected to an extraneous internal noise. Consequently, as can be seen, it is difficult to distinguish between the indoor extraneous noise source possibly from construction work in the residence and outdoor noise source from a train occurrence.

Figure 2 represents another frequent indoor noise distribution over time. As can be seen, there were activities at the beginning of a measurement whose $L_{\mathrm{Aeq,1s}}$ does not exceed 65 dB(A), which could perhaps suggest a conversation between residents, radio or television in use etc. After approximately 14:35, noise levels drop by around 20 dB(A) which indicates the end of the noise event and thus no internal noise source in a dwelling with low levels of background noise. For this particular measurement location, a road was situated between the receiver and the railway line. Road traffic events occurred with greater intensity than train pass-bys, the latter of which are scheduled as 4 per hour according to the National Rail timetable.

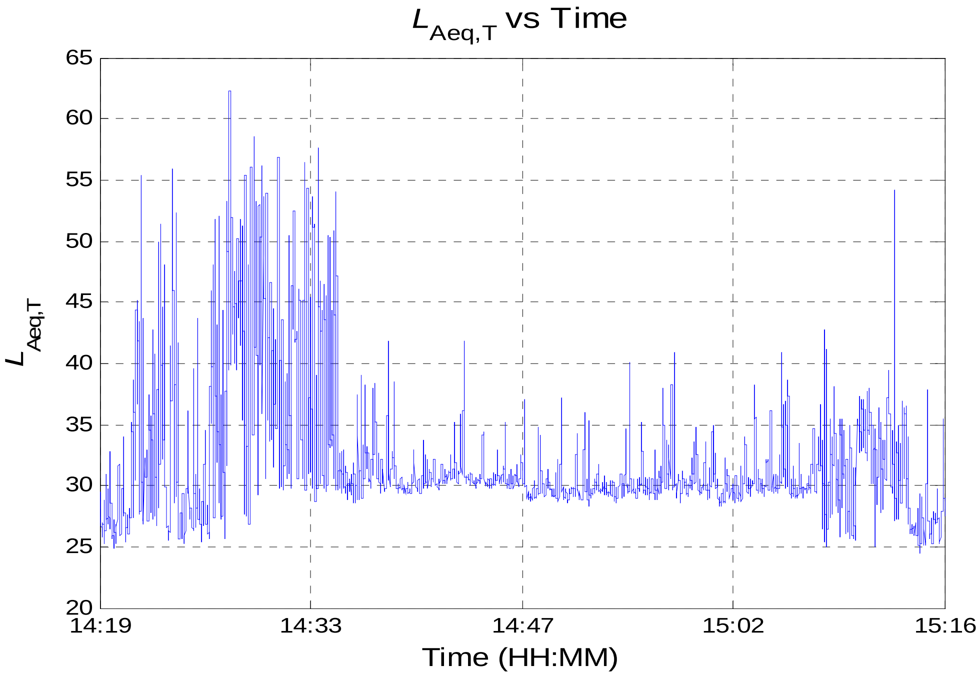

Figure 2 - internal noise measurement indicating initial activity within the residence, followed by a period of relative quiet. Train pass-bys were scheduled for approximately every 15 minutes, but the measurements do not indicate associated noise.

On the other hand, external measurements provided good results. A distinct number of events could be extracted from the overall signal. An example of such can be found in Figure 3. This is the result for a measurement conducted in Birmingham on the 26th of January 2010 in the morning period.

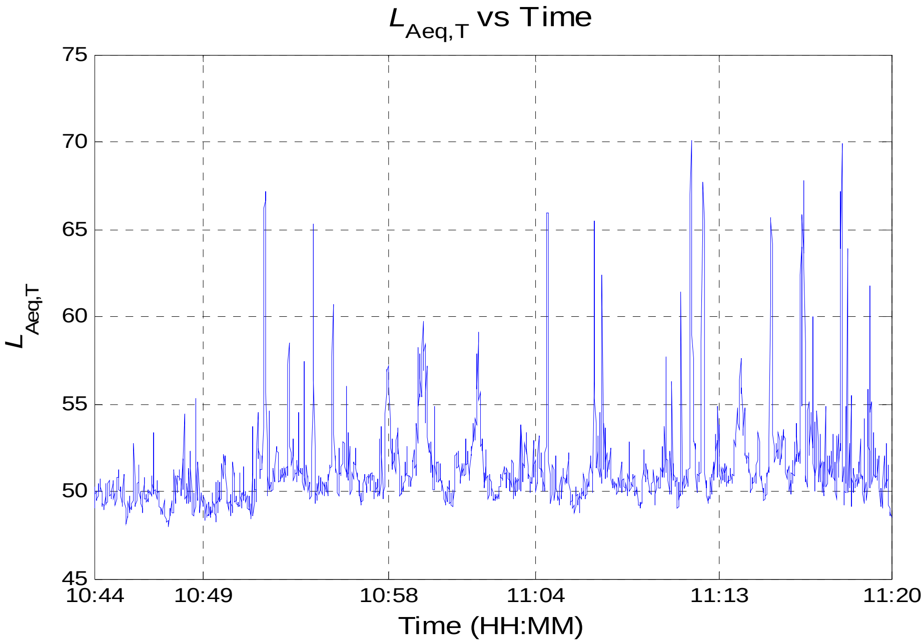

Figure 3. This figure presents external noise measurements. Most events can be identified and extracted from the data.

Figure 4 illustrates a shortened section of the measurement presented in Figure 3, which shows that three distinct events can be extracted from outdoor measurements. It should be noted that it is still not possible to identify such outdoor event occurrences as aircraft, trains or road traffic sources.

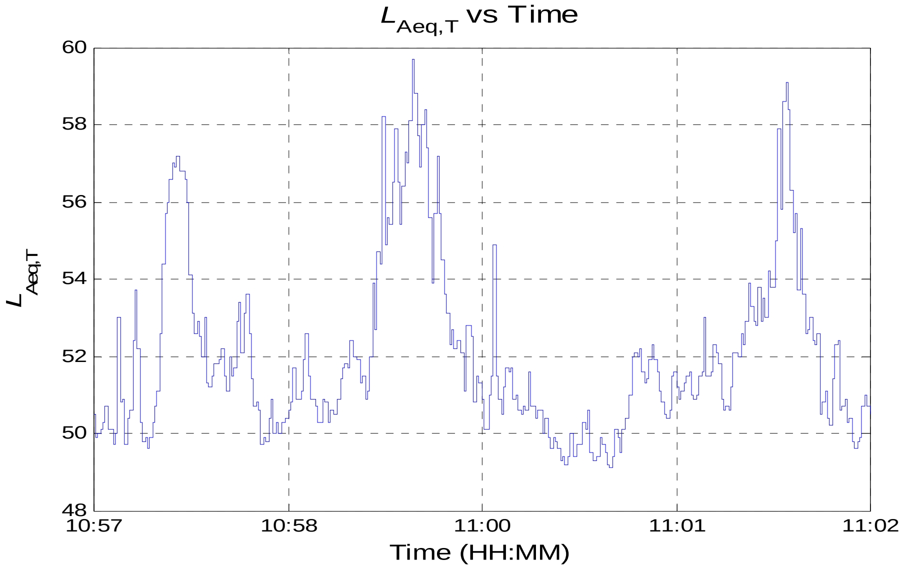

Figure 4. This figure presents a shortened segment of the measurement in Figure 3, indicating 3 separate noise events.

Table 1 presents the example of a few sound exposure levels. Due to different number of train occurrences, sound exposure levels vary from one site to another. All sound exposure levels in Table 1 are averaged.

Address	**Predicted L_{AE} dB(A)**
Site A, Street 1	91.7
Site A, Street 2	91.7
Site F, Street 1	90.9
Site F, Street 2	90.6
Site F, Street 3	88.9

Table 1 presents sound exposure levels from calculation. All values have been averaged due to different number of train occurrences which varies from one site to another.

Address	**L_{day}/dB(A)[9] predicted**	**L_{day} /dB(A)[9] measured**
Site A, Street 1	62.3	58.6
Site A, Street 2	58.6	58.1
Site F, Street 1	58.3	55.5
Site F, Street 2	57.9	54.7
Site F, Street 3	48.9	50.6

Table 2 presents a comparison between L_{day}[9] determined from Calculation of Railway Noise and Noise Map values obtained from Defra website.

Table 2 on the other hand shows comparison of L_{day}[9] from measurements on sites and prediction from CRN (Department of Transport, 1995).

As it can be seen, the values in Table 2 vary between prediction and calculation. CRN requires detailed information regarding trains, topography of a particular site location, attenuation from natural and artificial barriers as well as fairly accurate information about the noise sources themselves, whereas on-site noise measurements are representative of the true nature of noise at a given position. This may go some way towards explaining observed discrepancies. Additionally, measurements on site have been conducted during the day when freight trains could not be recorded. As a consequence, freight trains are not included in calculation of L_{day} from measurements giving much lower results. A final note should be made in terms of the results from predictions which make a number of assumptions, one of which refers to the velocity of a train. Train speeds has been acquired from two engineering reports issued by National Rail (Goffey, 2005; Moor, 2009) Depending on a site, it was considered that a train speed varies from 50 mph (80 kmph) for slow speeds, through 65 (104 kmph) mph or 110 mph (176 kmph) for passenger speeds, until maximum 125 mph (200 kmph) for Enhanced Speed Trains (valid for trains comprise of e.g. Class 390 class cars). A few train speeds limits are found to be reduced to 20 mph (32 kmph), however, this is rarely encountered and non of any sites were covered by this speed limits.

3.2.3 Observation

An important observation from the preceding section is that for environmental noise, a definite discrepancy exists between results obtained from internal and external measurements.

Figure 2 shows indoor activities such as conversation, radio, television etc. In terms of noise level arising from internal and external sources, differences indicate that external noise sources can be effectively masked by internal sources. A train passes by a reception point at this site regularly every 15 minutes. The figure presents some outdoor activities and perhaps it would even be possible to determine events from this signal. However, it is worth a note that in the part of the measurement corresponding to a period of low level of noise, external sources hardly exceeds 45 dB(A) whilst an average of level of an internal source is found to be about 55 dB(A).

Consequently, with results having such a low level due to corresponding external activities when measured inside a property, it is rather difficult in a typical house to determine an internal exposure from an internal measurement. It is thought that the best approach is to assume that external exposures correlate well with internal exposures. A number of documents regarding noise exposure, response and annoyance relationships (Schultz, 1978; Fields & Walker, 1982; Miedema & Vos, 1998; Miedema & Oudshoorn, 2001) rely on external exposure calculation with the same assumption.

Consequently, it is assumed from results in the previous section that determination of internal exposure cannot be obtained with sufficient accuracy from internal measurement. There is only a little evidence of a correlation between an internal and an external exposure but a few papers assume that the correlation exists although not having sufficient data (Shield & Dockrell, 2004; Graham et al., 2009).

Although two approaches were considered towards validating the results from the prediction, a more sophisticated method will be required. Such a validation would require more measurements to compare from different sites. Owing to time constraints, the acquisition of the required number of measurements is not currently feasible.

3.3 Noise estimation from Calculation of Railway Noise

This guidance document defines a routine covering all details influencing the final noise emission from railway vehicles passing by a point of reception. Additionally, CRN (Department of Transport, 1995) covers site topography, ground reflection, number of vehicles per train, number of trains per 24 h, air absorption (although this is primarily a high frequency effect), distance correction, barrier attenuation, reflections from facades as well as the reflective contributions of buildings surrounding the point of reception. The most significant and accurate approach, however, demands a great deal of specific information about sites which could not be obtained by the time of presenting these results. Consequently, the prediction is based on a number of assumptions, although final results do not seem to deviate. The number of trains was estimated based on extraction of events from control positions monitoring vibration from railway traffic for 24 h in the vicinity of rail lines. The details upon this topic can be found in Technical Report No 3 "*Calculation of Vibration Exposure*" (Sica et al., 2011).

3.3.1 Assumptions Imposed

CRN is a well established and accepted routine of predicting noise exposures from railway traffic. Nonetheless, the accuracy of the results depends on a great deal of factors influencing the final result. Assumptions are imposed in order to obtain reasonably accurate values of L_{den}.

The first of the assumptions refers to the train speed. Each train, and hence its constituent vehicles, has a maximum speed dependent upon the locomotive, e.g. Class 390 trains and use fast vehicles (Pendolino) whose speed can reach a speed equal to 200 km/h[5]. On the other hand, class of trains e.g. Class 170 (Turbostar) is able to reach a much lower speed probably not higher than 160 kmph.

Trains are comprised of a number of vehicles which also vary in terms of a sound exposure level correction. Class 390 uses trains comprised of 9 vehicles. All vehicles vary in terms of

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[5] 200 km/h is probably the limit imposed in UK as Pendolino trains get travel with speed greater than 200 km/h

their function. They can be Driving Motor, Intermediate Motor, or Intermediate Trailer etc. Trains such as Pendolino (Class 390) are called a multiple unit[6]. Despite the variation in terms of a vehicle function, a L_{AE} correction from a single vehicle for this class of train is found to be either 7.6 or 6.0 dB(A). There are number of configuration of trains which can be found in CRN. In terms of non-multiple units, a vehicle can be either a locomotive or a coach[7].

On the other hand, on local railway routes a number of 2 vehicles per train is very common. Due to these differences an average number of vehicles was assumed to be 5.

Noise emissions from a single vehicle are assumed to be constant for all constituent train vehicles, and so a correction of 7.0 dB(A) per vehicle was assumed.

Another assumption refers to the distance between rails and the point of response. This parameter was estimated from Google Maps. A different number of tracks can be found in different rail lines. CRN (paragraph 19) requires the source to be near-side rail head. Thus, the distance was assumed to be taken from the centre of the railway line to take into consideration both directions all trains travel.

Due to difficulties of recognizing and estimating the ground topography from aerial photography, the prediction of effects due to path length differences and shadowing induced by embankments and cuttings is included only as an uncertainty (Section 5).

Reflections from opposite buildings were not included in calculation which might cause a rise in uncertainties in a few locations.

3.3.2 Calculation

Calculations of noise exposure were conducted for passenger and freight trains. The number of trains was obtained from estimating times of all events from all control positions measuring vibration for 24h. If there were more than one control position, monitoring the same rail line (see Figure 5), an average number of train occurrences from all the control positions measuring the same line was calculated and used as a number of trains during a day-time, evening-time and night-time period. The average number had to be taken due to slight differences in detecting no of events from more than 1 control position. The differences were likely to occur and were expected as the monitoring was carried out in different conditions (e.g. an accelerometer was set up inside a property or outdoor, close to a railway or inside a shed etc.).

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[6] A multiple unit train can be electric or diesel abbreviated as DMU or EMU respectively. For instance Pendolino is an EMU train.

[7] The term wagon is used to describe a car which is part of a freight train carrying goods.

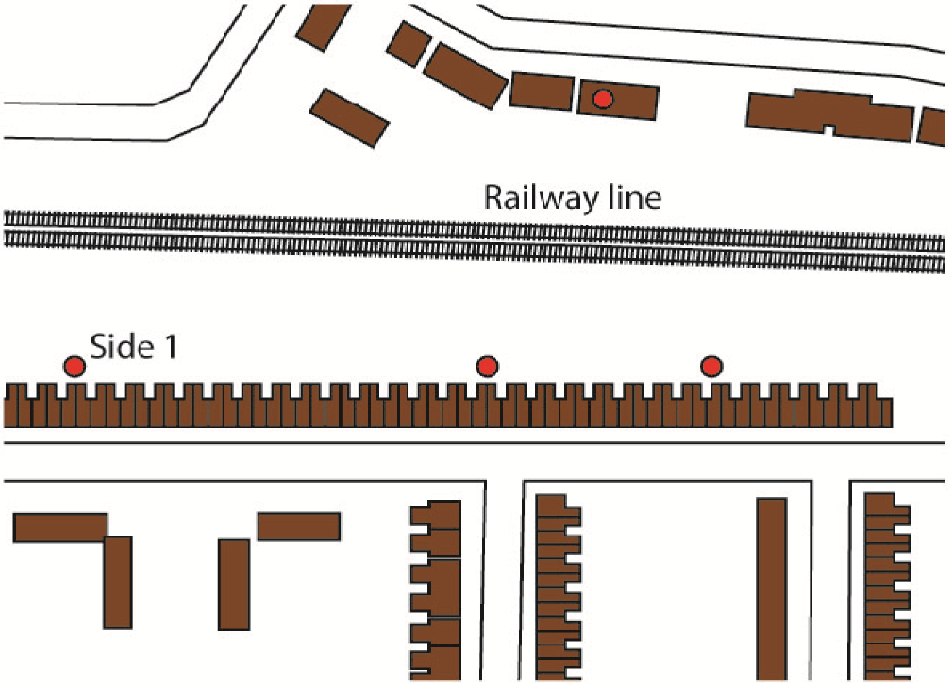

Figure 5 shows an example of 2 sites located close to each other. The same railway was situated in such location that all residents from different sites were exposed to noise and vibration from the same trains. The monitoring of vibration by all control positions took 24h, however, the measurements were started at different time.

Table 3 presents the number of control positions per site. The number of two control positions was common, although sometimes more instruments had to be set up. The number of control positions came from a limit that one instrument can measure vibration within a radius of 80 m. If a length of a site was found to be greater, then it was decided to set up a greater number of instruments.

Site	Number of Control Positions
Site A	2
Site B	2
Site C	2
Site D	2
Site E	1
Site F	4

Table 3 Number of Control Positions for different sites

The number of passenger and freight trains estimated for this railway line is presented in Table 4.

	Passenger	**Freight**
Day[8]	117	1
Evening[8]	40	1
Night[8]	23	2

Table 4 Example of estimating the number of passenger and freight trains on a site

The algorithm used for extracting particular events is explained in Technical Report 3 "*Calculation of Vibration Exposure*" (Sica et al., 2011). Numbers of freight and passenger trains for the other sites were estimated in the same way.

CRN (Department of Transport, 1995) gives a routine to calculate L_{dn} based on L_{AE}. For the purpose of this project (where the percentage of highly annoyed respondents is calculated based on L_{den}), the routine was subsequently adapted.

The routine for calculating L_{AE} and L_{den} for every respondent is as follows:

- A number of passenger trains and a number of freight trains during a day, an evening and a night was estimated from control positions
- L_{AE} corrections are assumed to be 7 dB(A) for passenger train vehicles, 14.8 dB(A) for a freight train diesel locomotive and 7.5 dB(A) for a laden freight train vehicle (wagon)
- Speeds of passenger and freight trains were assumed based on information provided by Network Rail
- The noise source position for passenger trains was set as 0.25m above ground for all vehicles except diesel locomotives operating under full power, which requires the effective source position as being 4m above ground level
- The distance between point of source and reception was calculated from aerial data, not including path length differences caused by embankments or cuttings
- Distances were estimated from Google Maps (Google Inc., 2011) and applied to calculations as an average between both railway lines
- Corrections due to the number of vehicles were applied separately for days, evenings and nights, and L_{AE} were calculated
- Sound pressure level for days, evenings and nights were calculated and finally L_{den} was obtained

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[8] According to EU Directive (Directive 2002/49/EC, 2002) day-time, evening-time and night-time periods are specified between 07:00 – 19:00, 19:00 – 23:00, 23:00 – 07:00 respectively

3.3.3 Results

This section presents results from calculation of 24h exposure to noise from railway traffic according to EU Directive (Directive 2002/49/EC, 2002) and associated European papers. The main noise descriptor used for expressing 24h exposure to noise is L_{den}. This descriptor includes a penalty imposed for evening and night events, in that a penalty of 5 dB(A) for evening time events and 10 dB(A) for night time events are added to all occurrences between 19:00 and 23:00 and between 23:00 and 07:00 respectively. This is a regularly practiced procedure for whenever a relationship between annoyance and exposure is analysed. The same procedure was assumed in this report.

Table 5 presents results of prediction obtained from calculation based on CRN. One of the main reasons for such results is that the greatest number of freight trains was encountered here at the time of measurement. Although such sites were subjected to a high frequency of freight traffic during the measurement periods, this would not necessarily be the case at other times. This is because freight trains do not travel regularly according to any scheduled timetable. The quietest observed site can be explainable by the fact that only a small number of trains are scheduled to pass the reception point. Additionally, no freight trains were encountered during measurements and none were extracted from the control position signals monitoring vibration for 24h. One has to bear in mind that the analysis is based on only 24h windows of measurements. In this time, freight train pass-bys may or may not occur.

	No of respondents	**Av. L_{den}**	**Min L_{den}**	**Max. L_{den}**
Site A	115	57.9	40.4	61.2
Site B	30	58.0	49.7	61.5
Site C	9	53.8	51.3	56.0
Site E	64	67.2	58.6	73.9
Site F	61	59.6	54.4	63.1
Site H	87	62.2	56.9	68.0
Site I	155	63.2	57.0	68.6
Site J	235	60.2	53.1	66.9
Site K	45	61.0	49.6	70.4
Site L	43	62.9	57.4	67.4

Table 5 shows values of calculated external noise exposures from CRN of all sites presented in three columns; an average, a maximum value and a minimum value. The results in the table consist of a combination of passenger and freight trains

Additionally, not all railways are dedicated to be used by freight trains, which is also the reason why some sites seem to be noisier among to the others.

Figure 6 to Figure 8 present frequency content of 2 passenger trains and one freight train. Figure 6 and Figure 7 show events conducted at two different sites but covered by the same railway line.

On the other hand, Figure 8 indicates a significant rise of noise in the middle frequency range and perhaps more associated tonal noise. One of the reasons this may happen could be that freight trains haul different type of wagons such as bulk cargo, containers, double-stack cars etc. An important fact is that empty cars produce much louder noise. Another fact is that freight trains are themselves much heavier than passenger trains, producing louder rolling wheel noise. Additionally, some freight wagons also tend to tread break, which can increase noise levels significantly (around 10 dB) as well as change the spectrum. Figure 8 seems to indicate a lower level comparing to other figures. Perhaps, this is due to the measurement, which was conducted at a greater distance from a railway.

Figure 6, Figure 7 and Figure 8 are also included in analysis for construction noise where frequency content of passenger and freight trains are compared with frequency content of construction noise.

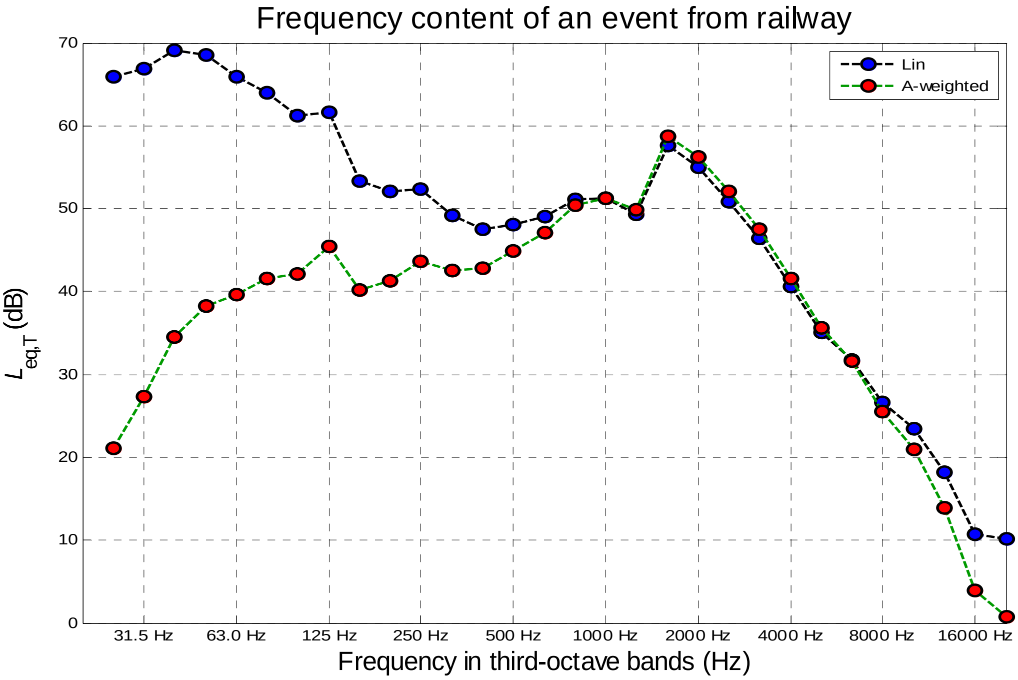

Figure 6 Third-octave band frequency domain signal with A-weighting from a measurement of a passenger train

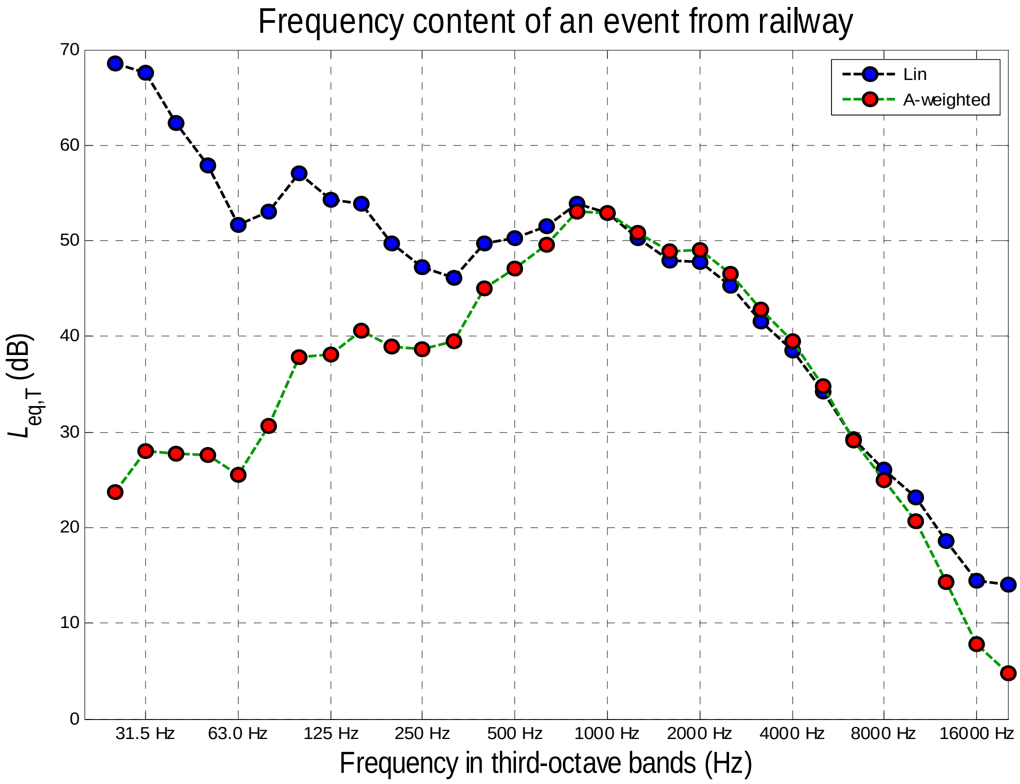

Figure 7 represents third-octave band frequency domain signal with A-weighting from a measurement of a passenger train

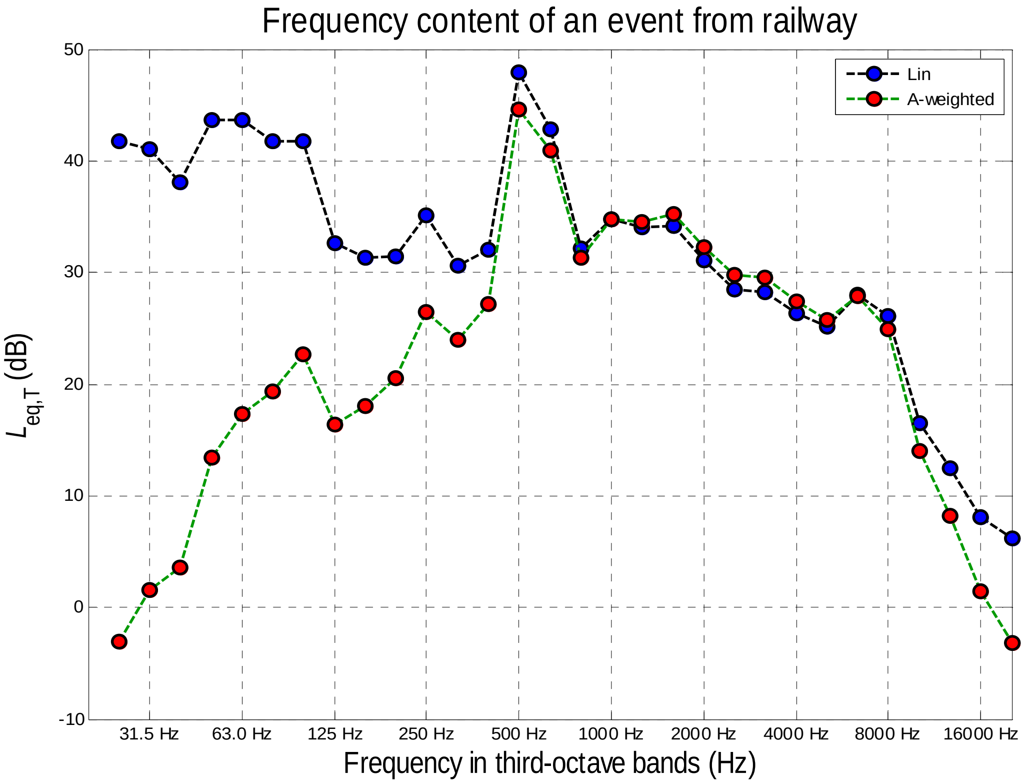

Figure 8 presents third-octave band frequency domain signal with A-weighting from a measurement of a freight train

3.4 Summary

In summary, due to logistical difficulties and limitations of performing the necessary number of measurements, human exposure to noise as an effect from railway traffic was calculated from prediction rather than measurements. A few reasons were mentioned in the previous sections. It can be seen from validation that the prediction gives reasonable results which could be used for investigating human response to noise. It would be preferable to take measurements at all sites where vibration was previously monitored. Assumptions made for predictive purposes are likely to introduce errors into the final calculated results, whereas measurement would give a more accurate indication of the noise environment at each site.

4 Determination of noise exposure for Construction Sources

4.1 Introduction

In this section the methodology, results, calculation and estimation of exposures and analysis are considered for construction noise. The results are presented in terms of noise level according to noise descriptors such as $L_{\mathrm{Aeq,T}}$, L_{A10}, L_{A90}, and L_{AE} (sometimes denoted as SEL). The section ends with conclusions and observations associated with the prediction of noise exposure due to construction.

4.2 Noise measurement overview for construction sources

Noise exposure was calculated based on measurement of noise at sites in Manchester

- South Manchester
- East Manchester

Construction work occurred there due to building new tram lines.

A number of differences were found in terms of noise exposure and measurement at each site. The main difference relates to the character of the noise source and its frequency content. Piling for instance was found to occur in Southern Manchester, and can be characterised as an impulsive noise whereas much more uniformly distributed noise sources were evident in East Manchester. Extraneous noise sources, particularly that of background noise, significantly influenced the measurements during construction work, especially in East Manchester.

South Manchester construction was situated in a much quieter area, located a significant distance from any other extraneous environmental noises such as road traffic. Despite this, it cannot be assumed that extraneous noise exerted no influence upon measurements. Moreover, a number of aircraft flyovers were also recorded. No practical limitations were encountered in installing an instrument at the required position, close to a source. In terms of recording the events themselves, a significant problem remained due to difficulties in anticipating the construction work schedule.

On the other hand, the East Manchester site was located directly beside a main road. The intense road traffic encountered at this site was therefore a contributing part of the noise exposure, contaminating the measured sources. As such, at most times a measurement of mixed sources took place. Limitations were also encountered due to problems of installing the equipment. Little or no surrounding space remained for public access and thus for finding a receiver position in the vicinity of the construction area.

4.2.1 Methodology

Exposures for construction sources were estimated in a manner similar to calculation of railway noise. BS 5228-1:2009 seemed to provide the most relevant methodology to estimate daily exposure. As such, a well defined routine for calculation of noise exists for stationary and moving sources along a well defined path, as well as mobile sources within a specified area. In situations when both sound pressure level and sound power level are unavailable, tabulated values are given for separate octave bands. Frequency content of a noise source is important for an analysis of noise influence on residents behind barriers or obstacles because the shielding of sound propagation is frequency dependent. On the other hand, for the prediction of noise exposure, a noise source can be obtained from measurements of sound pressure level or sound intensity level. For the following methodology, sound pressure level was considered preferable.

All noise descriptors such as $L_{\mathrm{Aeq,T}}$, L_{AE}, L_{A10} and L_{A90} were normalised to a 10m distance between the source and reception point and an equivalent-continuous sound pressure level was adjusted to a 10h period, as per BS 5228-1:2009. All sources can be logarithmically summed by the formula below

$$L_{Total} = 10\log\left(\frac{\sum_{i=1}^{n} t_i 10^{0.1L_i}}{\sum_{i=1}^{n} t_i}\right) \qquad \textbf{Equation 2}$$

For calculation the level was adjusted to a 10h period, and so sources were summed and divided by their number

$$L_{Total} = 10\log\left(\frac{\sum_{i=1}^{n} 10^{0.1L_i}}{n}\right) \qquad \textbf{Equation 3}$$

Construction work was performed along the main road (East Manchester) and an approximately straight line (South Manchester) as can be seen in both Figure 9 and Figure 11. This allows the assumption of a line source in both cases. Consequently, a daily exposure (10 h; 07:00 – 19:00) was calculated from the middle (of the assumed line) of construction sites for both areas in South and East Manchester. After all sources were adjusted to a distance of 10 m, daily exposures from construction work were obtained by applying distance corrections between the most exposed façades of all houses and positions in the construction area. Figure 10 provides with additional information regarding the topography at the site (South Manchester). As it can be seen, the construction work was located the level below an instrument. This certainly has an influence to final results from all measurements at this site.

Measurements (which can be found in Section 4.2.3) had to be conducted in a different way in East Manchester due to space limitations. On the other hand, a more direct path with almost no obstacles was found in South Manchester where sources were situated in front of the measuring equipment. Depending upon particular event occurrences, some sources were situated with a ground level lower than that relative to the position of the receiver (Figure 10), but in terms of piling, the source was found to be at higher position than the sound level meter. Figure 9 also presents an aerial view of this site. On the other hand, in East Manchester the sound level meter was positioned in a free field as no façades were evident in the immediate vicinity.

4.2.2 Measurements

In South Manchester (Figure 9), a sound level meter was set up about 15m away from sources or the determining route of a mobile source. The sound level meter was set at a distance of 1m from the most exposed façade at a height above a ground of 1.5 m.

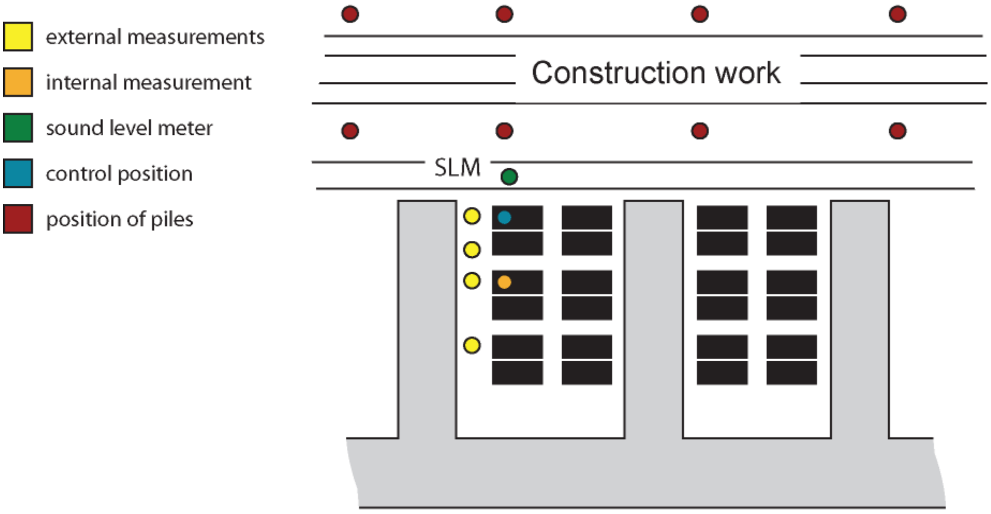

Figure 9 Top-down view of a site in South Manchester. Positions of all instruments are indicated in different colours.

The sound level meter maintained its position for all measurements over different days unless more important noise sources were observed at different parts of a site. The meter location was such that it always remained within the vicinity of a long-term vibration monitor.

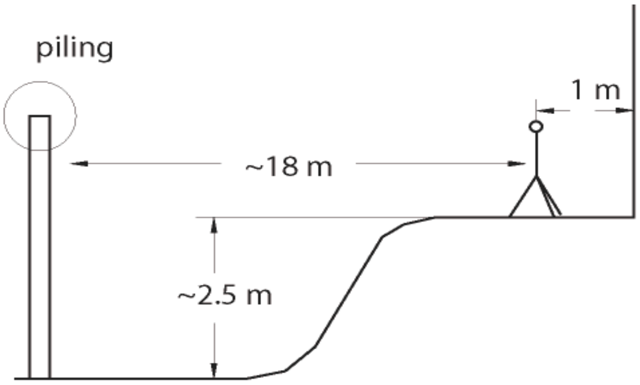

Figure 10 shows a position of a noise source and a sound level meter during the measurement for construction sources (South of Manchester).

As mentioned before, setting the position of the instrument in East Manchester (Figure 11) was not as flexible as in South Manchester. Limitations were caused by the reduced area accessible to the public and consequently for a position at which the sound level meter could be installed. As such, the sound level meter was set up in a free field away from any exposed façades. The height of the instrument remained at 1.5 m. At some time periods the path between the instrument and noise source was screened by buildings or high concrete fences and consequently a reduction of sound level was sometimes observed which is included in the calculation of uncertainties.

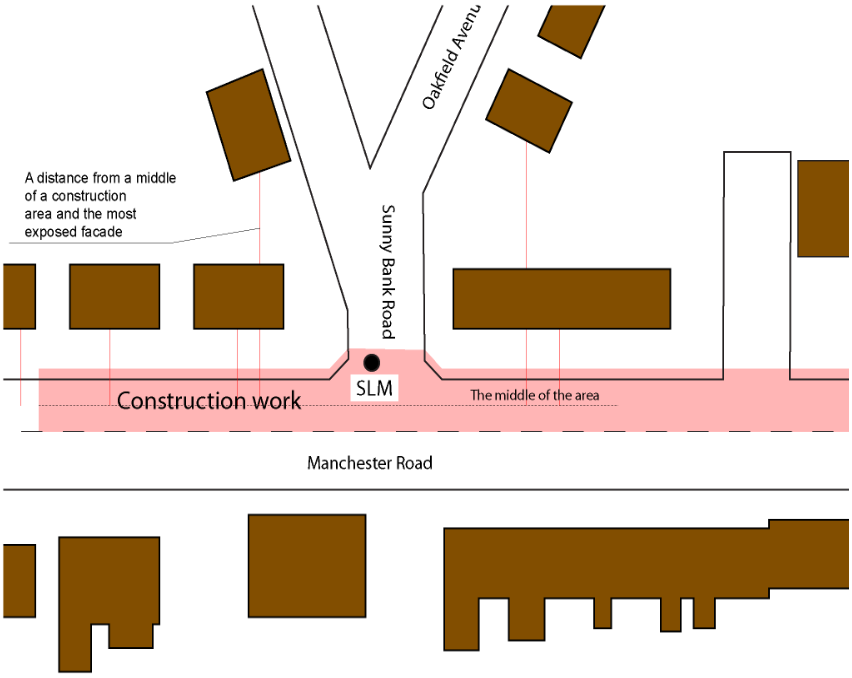

Figure 11 The construction site in East Manchester

The character of the majority of the noise encountered in South Manchester and nearby sites arises from piling processes. Sound from piling was found to be a loud tonal impulsive noise. Due to this impulsiveness of the noise, the sound level meter was set to measure both L_{AF} and L_{pF}, allowing more accurate recordings of the noise distribution peaks.

4.2.3 Results

This section provides results from calculation and prediction of noise exposure from sources associated with construction work. Results are presented in terms of level of noise exposure and frequency content.

Level of noise from construction sources

Noise levels against the percentage of residents exposed to the corresponding noise from construction sources is given in Figure 12[9].

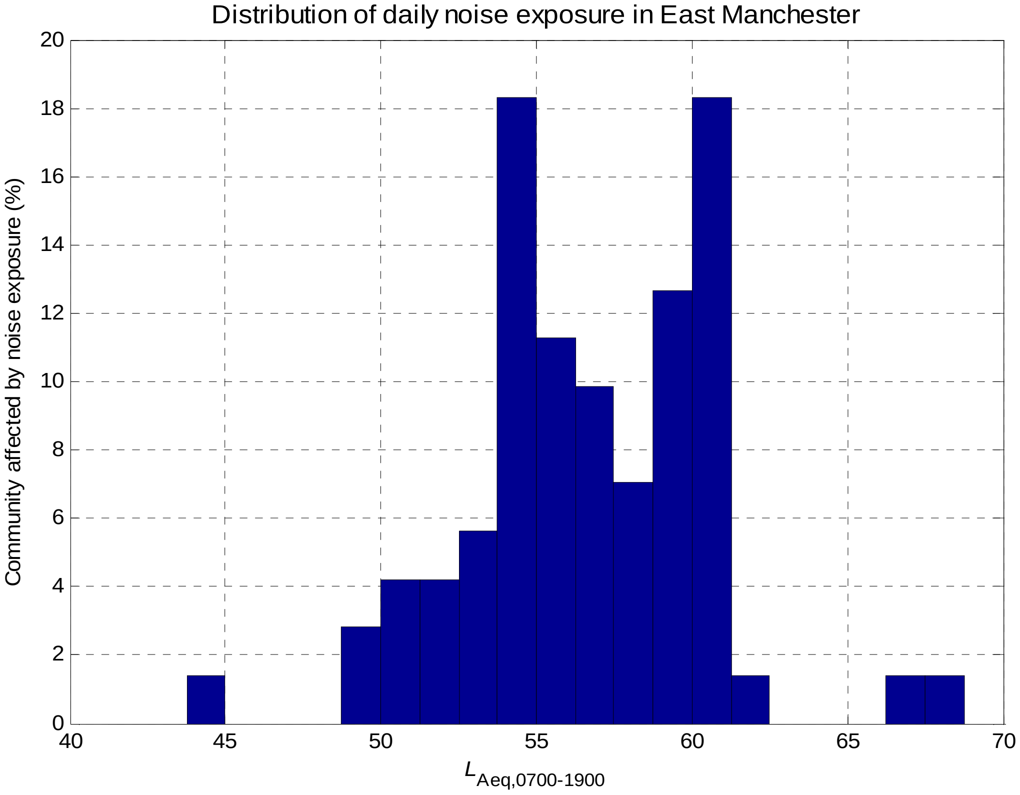

Figure 12 presents the histogram - the percentage of residents who were exposed to corresponding noise levels; East Manchester

Exposure levels are in the range of 43 to 70 dB(A). The largest percentage of residents are subjected to less than 70 dB(A). A significant amount of noise lies within the 55 - 70 dB(A) category and a lower percentage of residents were subjected to levels of 50-55 dB(A).

In South Manchester, exposures fell into range of 45 - 75 dB(A) with more uniformly distributed noise levels (Figure 13). The most frequent levels of noise exposure can be found between 52 and 56 dB(A), at 68 dB(A) and at 72 dB(A).

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[9] Officially, L_{day} described by EU Directive (Directive 2002/49/EC, 2002) is an A-weighted long term average sound level determined over all the day periods of a year. The definition of L_{day} can be also found in ISO 1996-2:1987. In this report, in terms of construction, the term L_{day} refers to an A-weighted daily average sound pressure level over the periods between 0700 and 1900 and is the same as $L_{Aeq,0700-1900}$.

In terms of railway noise the term L_{den} still refers to an average annual daily noise exposure

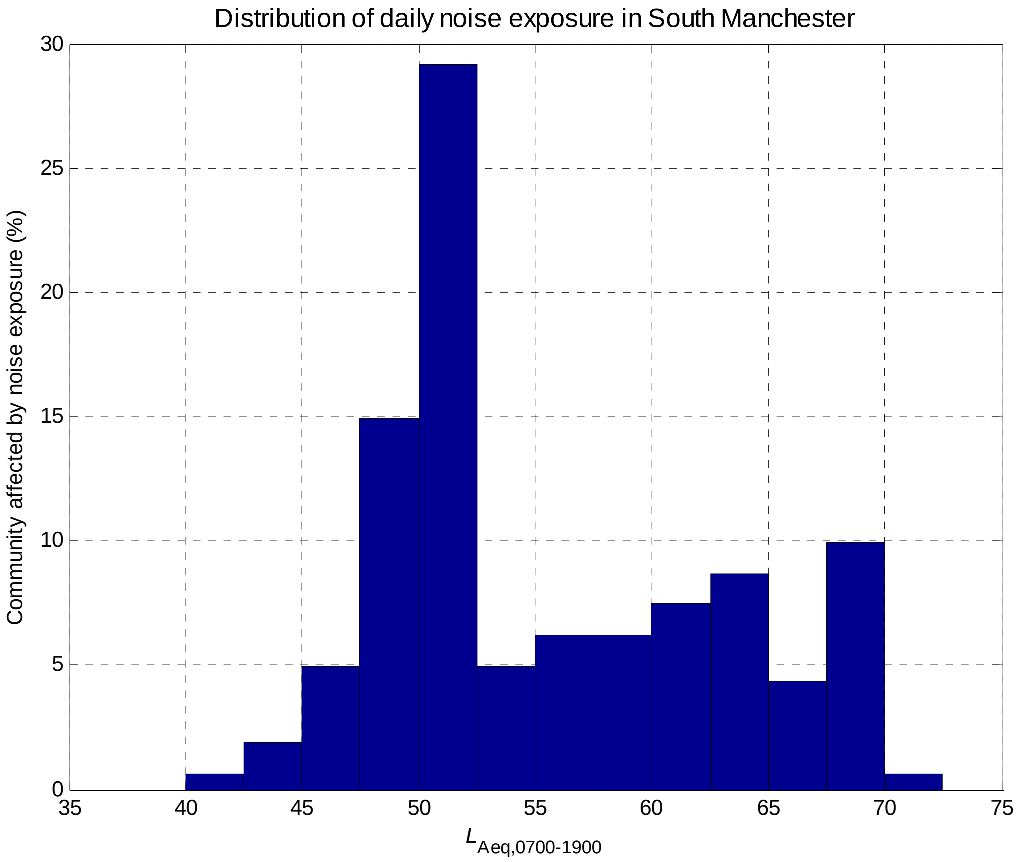

Figure 13 Histogram presenting the number of residents who were exposed to noise levels; South Manchester

Figure 14 and Figure 15 provide an indication of noise level decay with increasing distance between source and receiver. Results from East and South Manchester are shown in Figure 14 and Figure 15 respectively.

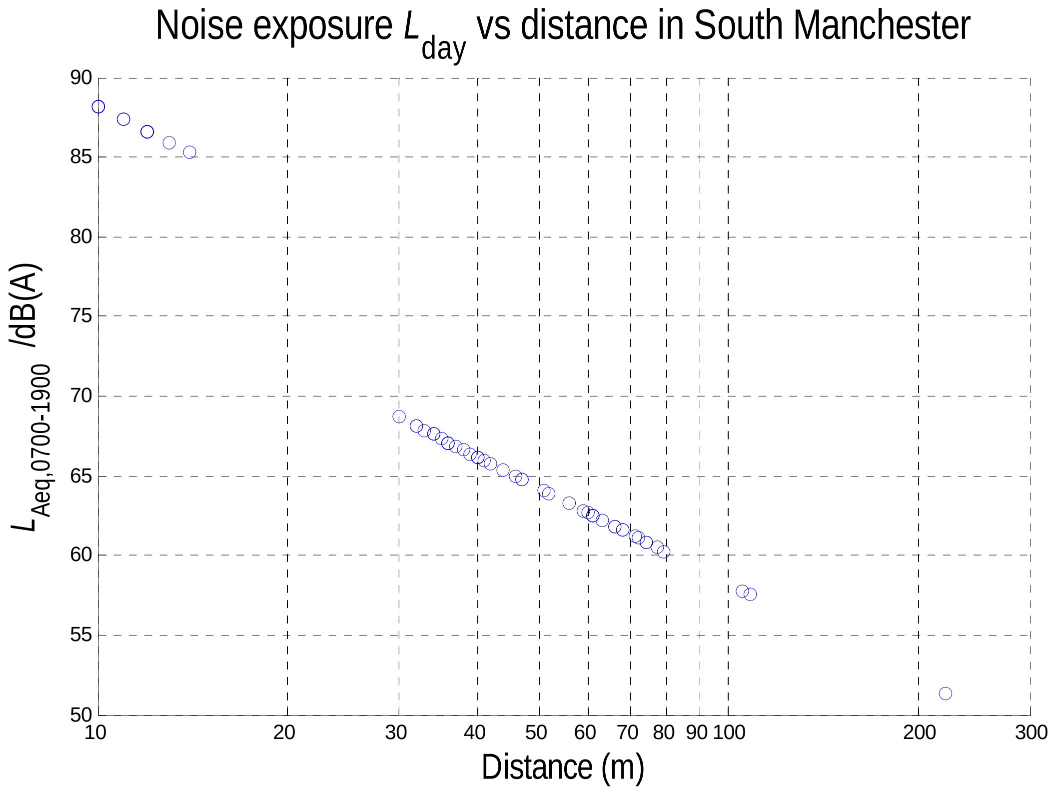

Figure 14 Relationship between distance and daily noise exposure (East Manchester).

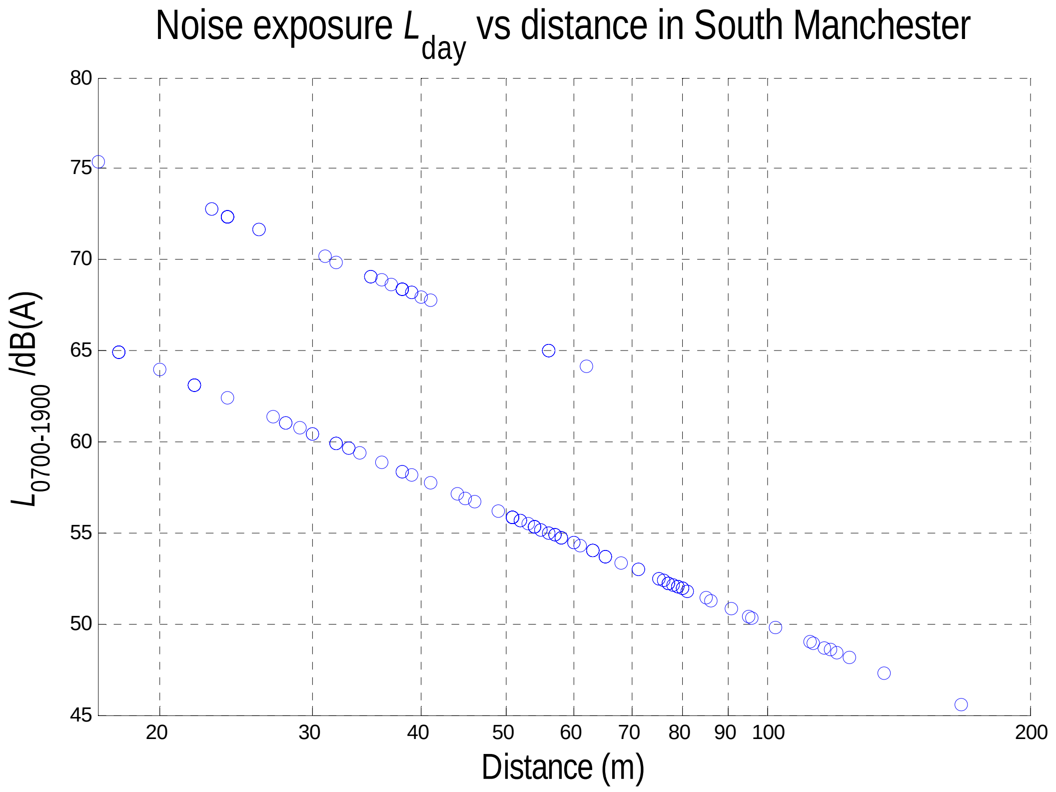

Figure 15 Relationship between distance and daily noise exposure (South Manchester)

Graphs were drawn using a logarithmic scale because of non-linearity of the relationship.

A simple statistical calculation is shown in Table 6. It indicates two factors; variations in terms of daily exposure and large variations in the distance between source and reception points.

L_{day} (dBA)

Site	Average	SD	Min	Max
Site_A	57.2	6.5	43.3	73.2
Site_B	63.8	7.1	53.6	70.2
Site_C	51.1	4.1	45.9	67.7

Distance (m)

Site	Average	SD	Min	Max
Site_A	48.8	25.3	17.0	167.0
Site_B	36.8	11.4	24.0	51.0
Site_C	75.0	24.7	30.0	124.0

Table 6 The first table presents average, standard deviation, minimum and maximum daily exposures to noise in South Manchester; the second table presents average, standard deviation, minimum and maximum source-to-receiver distances in South Manchester

Table 7 presents a single site where noise and vibration measurements were conducted. As can be seen, standard deviation of distance in East Manchester is much higher than in South Manchester. This means that many reception points were located a significant distance from the sources, implying an increased likelihood that propagation may be obstructed due to intervening terrain and barriers/obstacles.

L_{day} (dBA)

Site	Average	SD	Min	Max
Clayton / Droylsden	67.2	12.0	45.1	81.9

Distance (m)

Site	Average	SD	Min	Max
Clayton / Droylsden	39.4	33.1	10.0	220.0

Table 7 The table presents average, minimum and maximum levels and distances for a site in East Manchester

Plant / equipment	Operator, L_{Aeq}	
	Ave.	Range (dB)
Saw cutting	83.7	79.9 - 87.1
Excavating	74.4	53.5 - 81.0
Carrier	86.8	85.9 - 87.4
Breaker	84.7	76.7 - 87.3
Piling	87.8	86.3 - 89.0
Vibration machine	69.7	65.0 - 72.0

Table 8 Noise levels from construction work (South and East Manchester) normalized to 10m distance

Frequency

Although differences of noise exposures can be found in terms of noise levels, there are also variations caused by differences in frequency content. Results in the frequency domain are presented in the following figures. Firstly, adjustment was done just to visualise the difference between non-weighted and A-weighted frequency response, the latter of which accounts for the non-linear behaviour of the human auditory system. Secondly, another adjustment was made in terms of a distance. As distances varied from one measurement to another, sound pressure levels had to be corrected to normalise all results and simulate the scenario that all sources were located from the sound level meter at a distance of 10m. A-weighting correction was conducted according to the curve presented in the Figure 16, which is calculated from the formula below

$$\begin{aligned} W_A(f) &= 10\log_{10}\left(\frac{1.562339 f^4}{\left(f^2+107.65265^2\right)\left(f^2+737.86223^2\right)}\right) \\ &+ 10\log_{10}\left(\frac{2.242881\times10^{16} f^4}{\left(f^2+20.598997^2\right)\left(f^2+12194.22^2\right)}\right) \end{aligned}$$

Equation 4

This formula was reproduced from DiracDelta.co.uk (Dirac Delta Consultants Limited, 2001-2011) website.

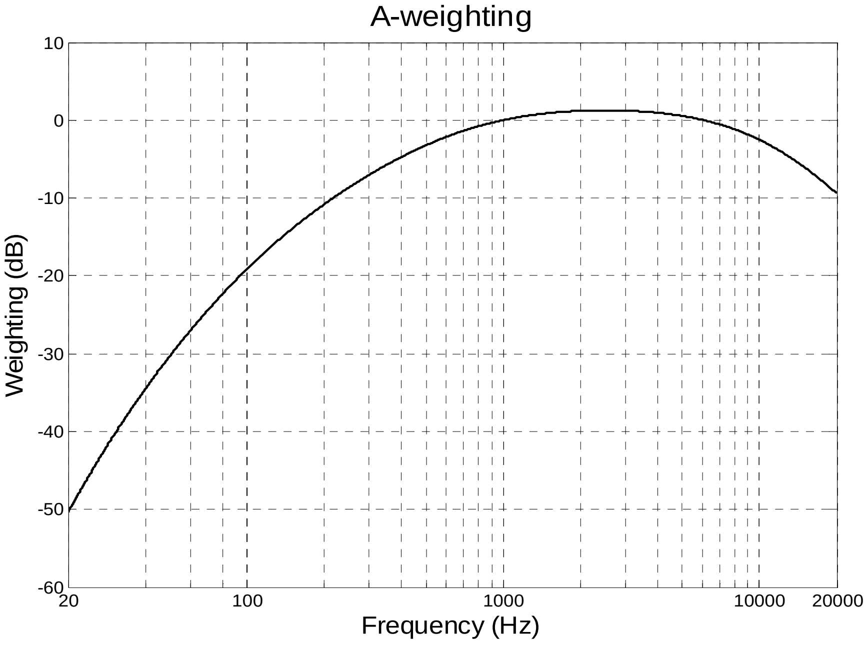

Figure 16 A-weighting curve according to which all adjustments were conducted to obtain results in frequency domain which are similar to how a human auditory system perceives sound

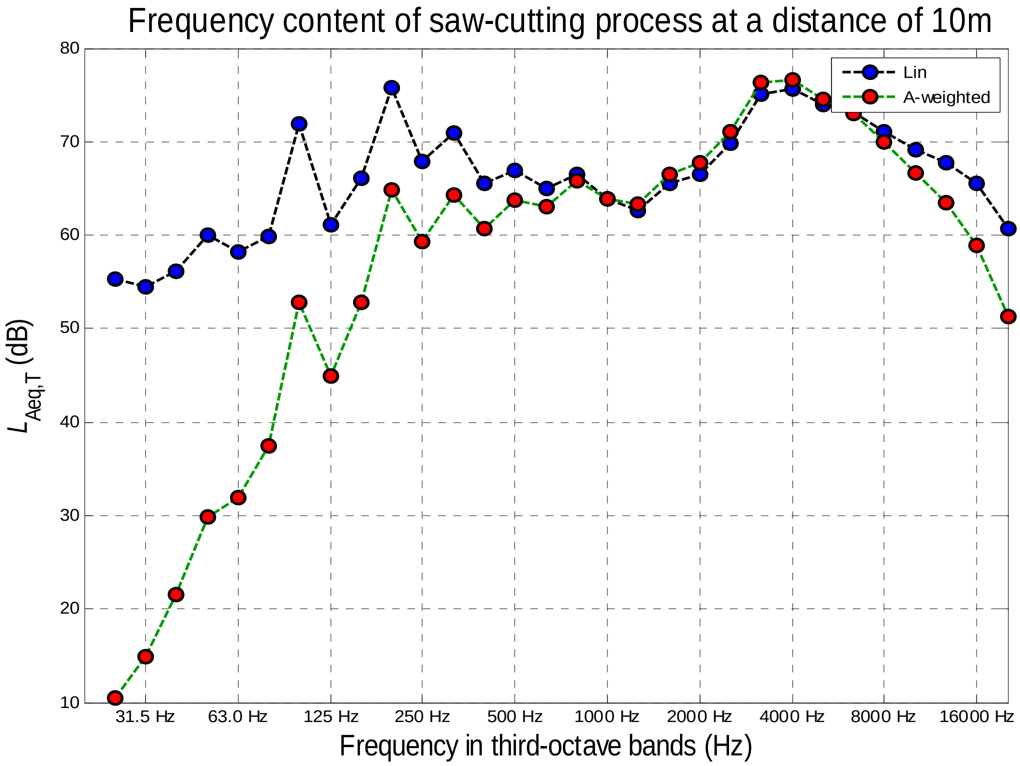

Figure 17 Frequency content presented in third-octave bands of one of the saw-cutting events in East Manchester where construction was done in the main road

Figure 17 and Figure 22 present results in the frequency domain of third-octave bands from two events; saw-cutting asphalt and piling respectively. These sources are characterised by significantly high mid-frequency range. As explained in the analysis section this is perhaps caused by rapid changes of pressure by vibrating components or the impulsive character of the noise, as shown in Figure 18 and Figure 19.

The other sources presented in this section come from measurements of a breaker of asphalt (Figure 18), ground excavating process (Figure 19) and the process of flattening by a steam-roller (Figure 20), all of which are machines and plant which play supportive roles on construction sites but which are however very loud. Also presented are results from all manner of carriers e.g. rail carriers during rail installation (Figure 21) and a machine which caused ground vibration (Figure 23). The latter process was observed every time a piling process had been completed.

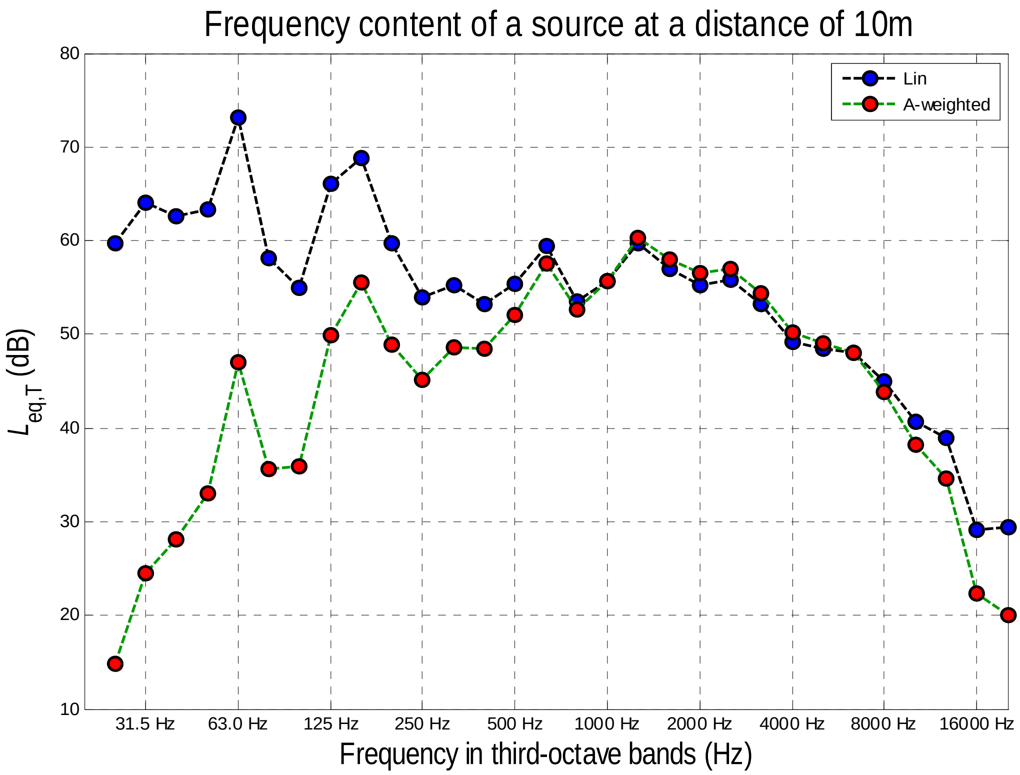

Figure 18 Frequency content of a breaker of asphalt in East Manchester

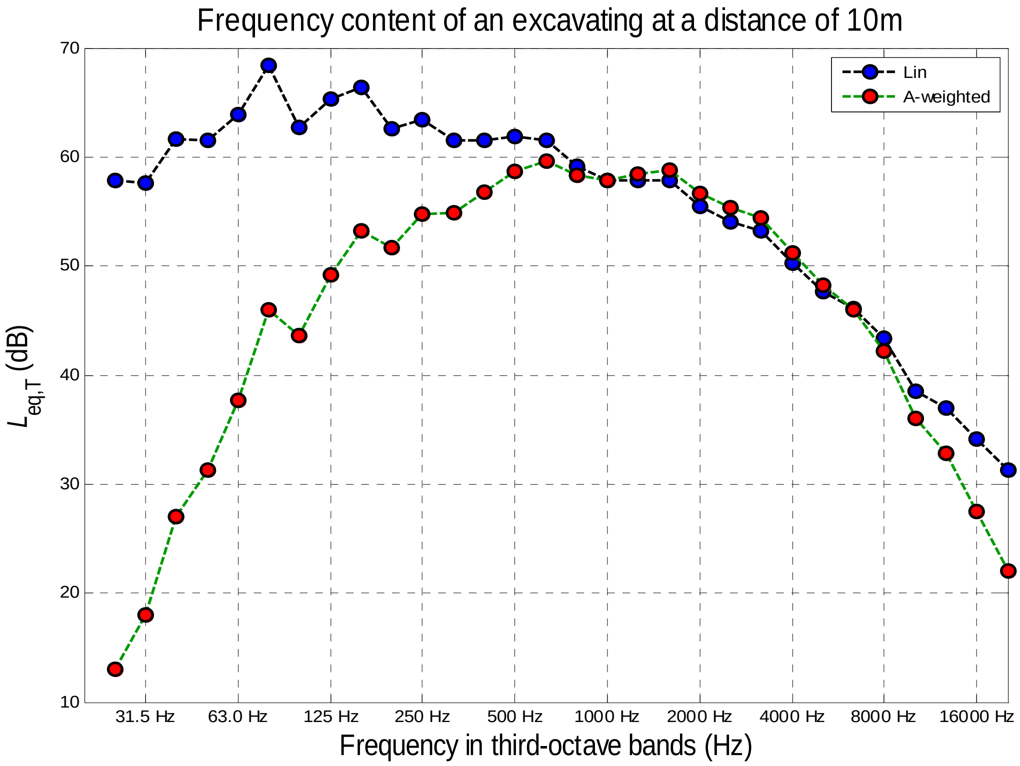

Figure 19 Frequency content of an excavating process in Eastern Manchester

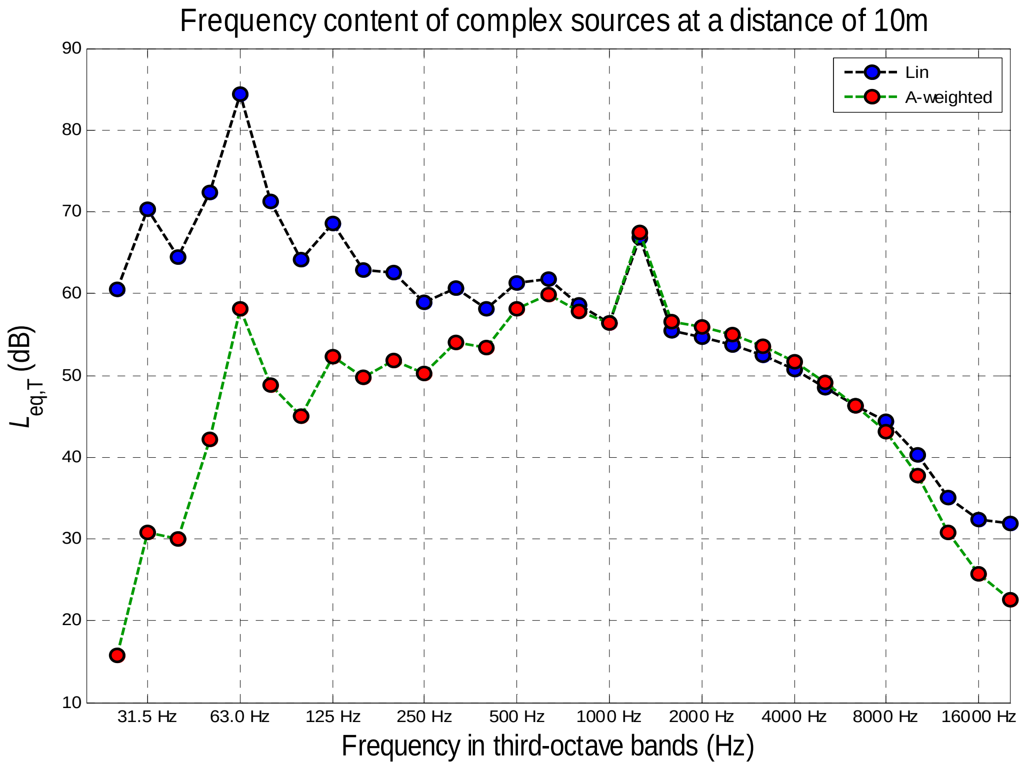

Figure 20 Frequency content of a steam-roller in East Manchester

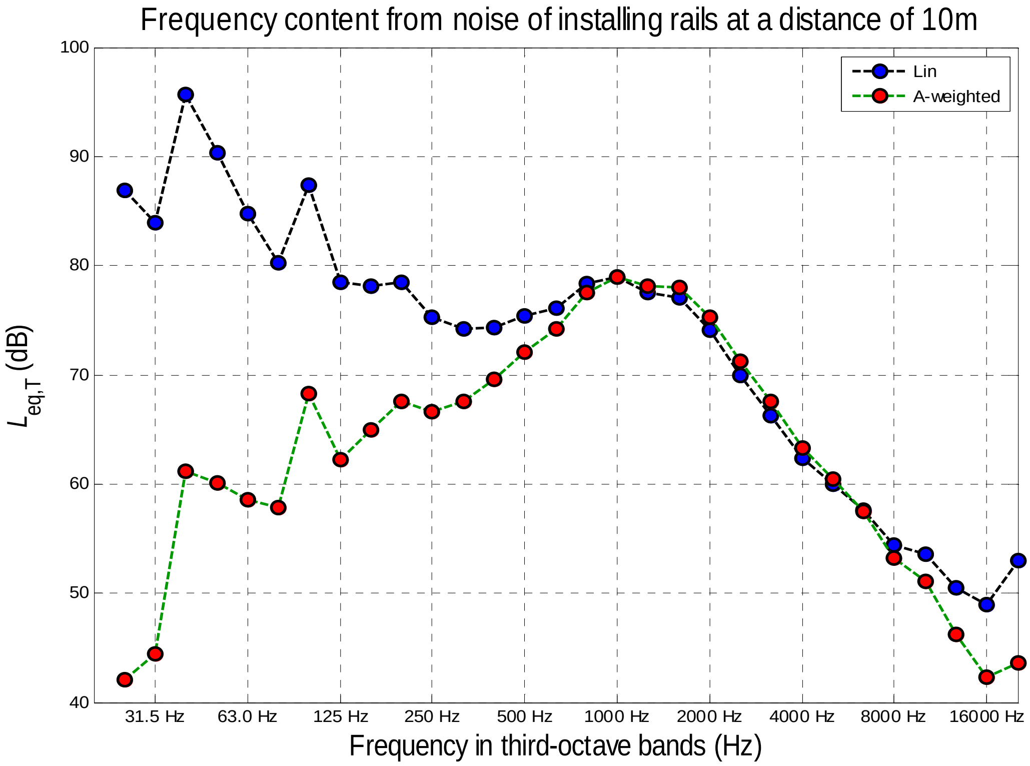

Figure 21 Frequency content from the measurement of a carrier. The data presented by this figure are normalised to 10m

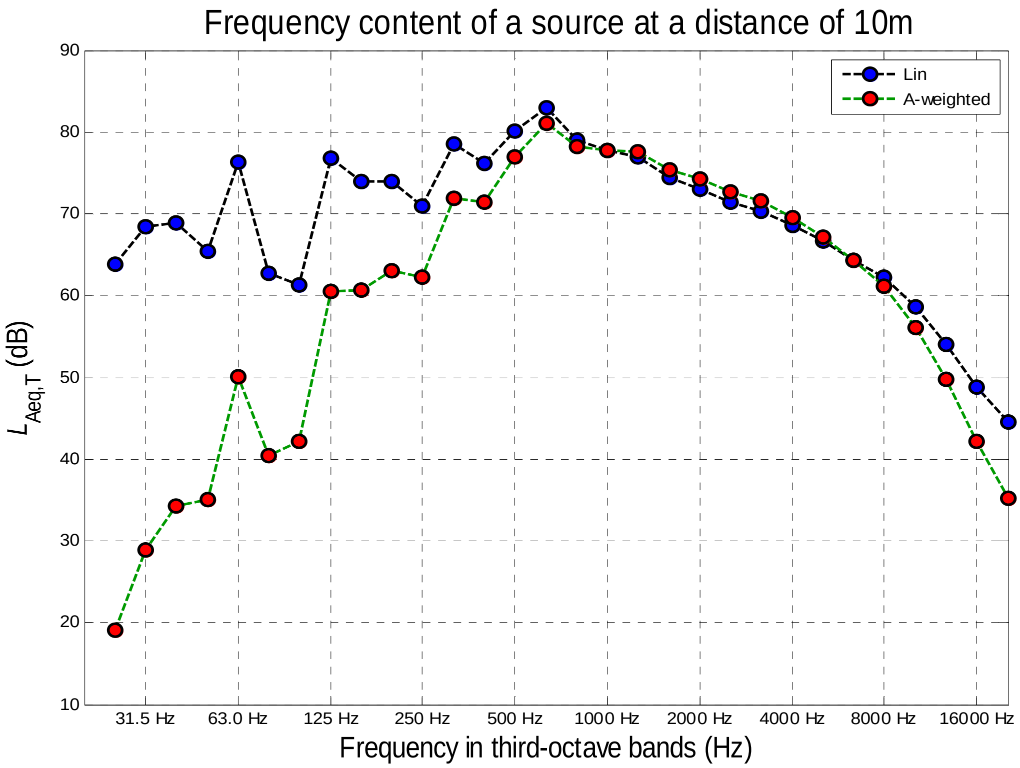

Figure 22 Frequency content of a piling process in South Manchester. The recording was done at a distance of 13m and normalised to a distance of 10 m

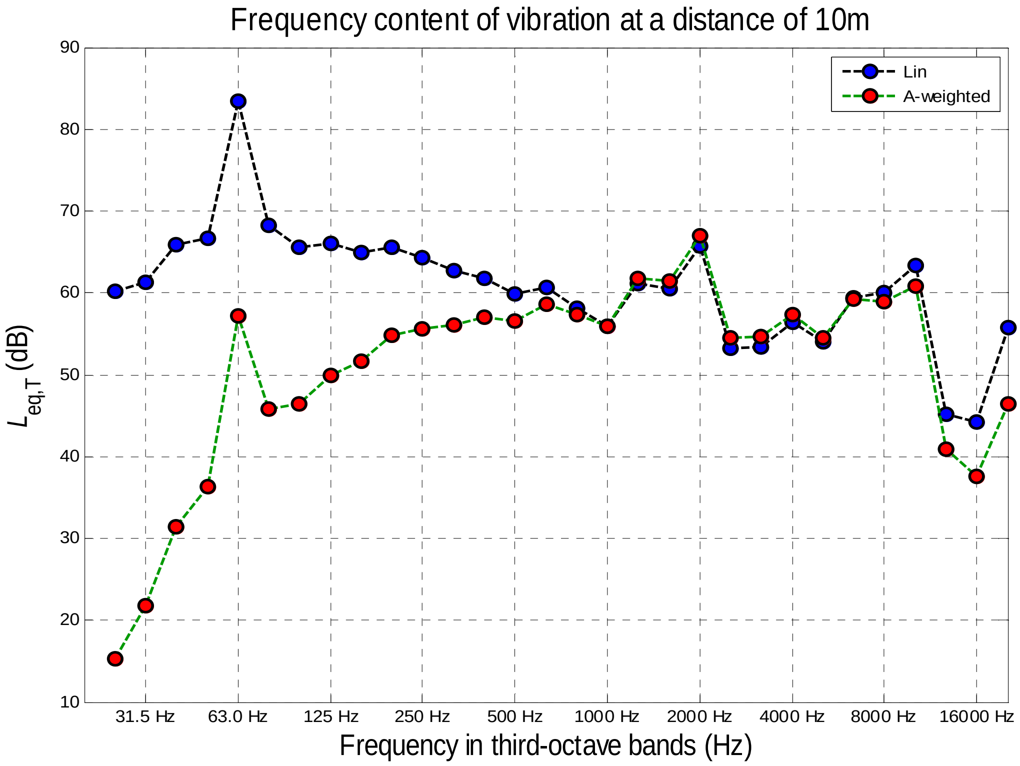

Figure 23 Frequency content of a vibrating machine in South Manchester

4.2.4 Analysis

The following chapter considers analysis and observations of the results presented in Section 4.2.3.

In general, noise levels of construction sources vary significantly in comparison with those from railway traffic. However, noise exposure is found to be different due to other factors such as frequency content. In terms of construction sources, such as saw-cutting and piling, residents may be subjected to impulsive tonal noise. Noise emissions from trains were found to be quieter and steady with a dominant low frequency range (Figure 6 and Figure 7). Low frequency tones are less likely to be perceived by residents due to the limited ability of hearing in this frequency region.

Figure 17 to Figure 23 present the variations in terms of frequency of particular sources. Comparing frequency content of plants working on construction and railway traffic sources a large difference was observed at low and high frequencies (Figure 24). The low frequency components of sound propagate more readily through obstacles. Figure 21 is an example of such an observation.

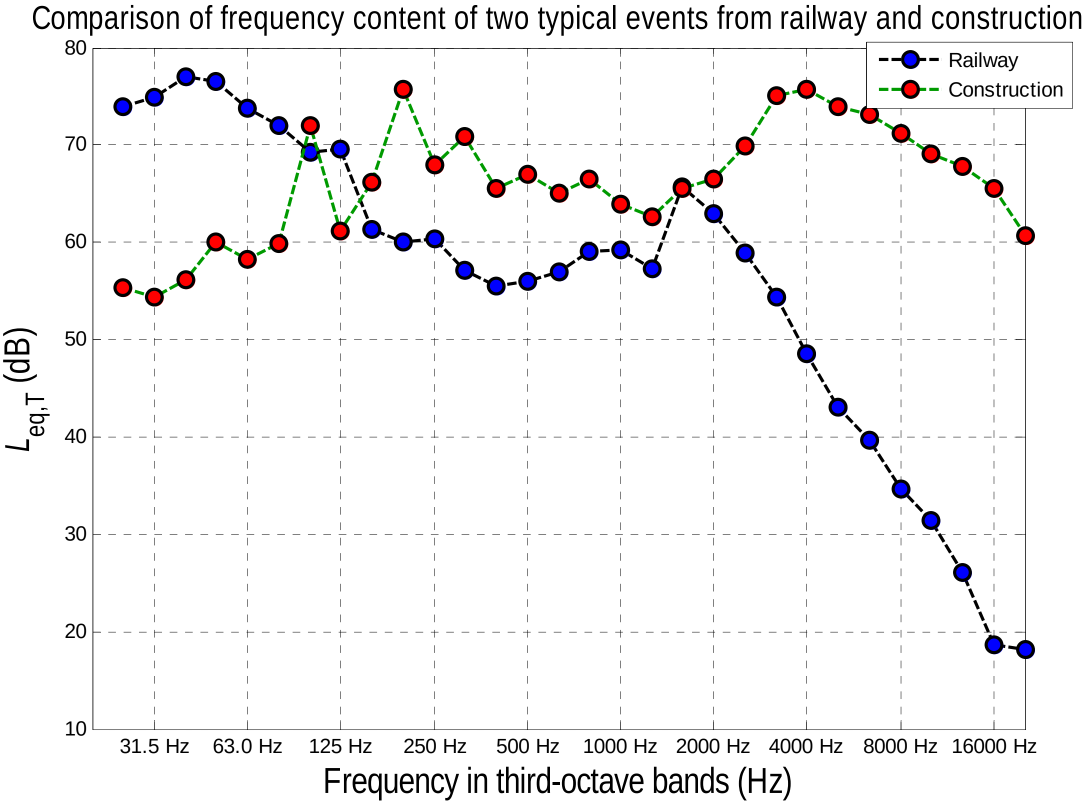

Figure 24 shoes the comparison of two typical events from railway and construction. Both noise levels are normalized to 10 m

Variation in terms of noise level can be found at both construction sites. One of the most important determining factors of this is the distance between point of source and point of receiver. This is shown in Figure 14 and Figure 15 and Table 6 and Table 7. Additionally, as the straight line distance between source and receiver is increased, so too does the number of intervening obstacles which act as effective barriers for sound propagation, thus further reducing noise exposure.

It can be noted that the frequency components in the range of 250 Hz to 4kHz dominate in Figure 17 and Figure 22. On one hand, saw-cutting gives extremely intensive loud noise exposure of rather uniformly distributed energy over time. According to Figure 17, such noise gives higher frequency components. On the other hand, piling (Figure 22) also produces higher frequency components in the range of 250 Hz to 2kHz. Piling has a more impulsive character of noise which could perhaps be subjectively perceived with greater annoyance. The higher frequency components stem from the fact that a hammer hitting a pile causes rapid dynamic changes in terms of sound and energy. It causes emission of partials? which can comprise higher frequency range tones. All sources, characterized by less impulsiveness, which exhibit fewer rapid dynamic changes to sound, represent lower mid and high frequency values, such as steam-roller and carriers (Figure 20 and Figure 21 respectively).

4.3 Estimation of noise in absence of measurements

Although ideally the noise exposure would be estimated from measurement for each case study, in this instance this is not possible due to the dimensions and duration of the construction and the large number of properties exposed to noise from operations. In these circumstances it is necessary to predict the noise from the construction operations. The methodology selected here is that presented by BS 5228-1:2009. The prediction of construction noise exposure is aided by long term vibration measurements that can be used to identify operations. The use of on-site measurements to determine the sound pressure of each operation reduces the uncertainties arising from the estimation

The factors considered are:

- The sound power outputs of processes and plant;
- The periods of operation of processes and plant;
- The distance from sources and receivers;
- The presence of shielding, screening and barriers;
- Reflection of sound;
- Soft ground attenuation;

Meteorological factors might also become significant if the distance between the source and receiver is greater or equal to 50m. The details regarding calculation of noise in the absence of measurement can be found in BS 5228-1:2009.

4.4 Summary

There were a number of practical issues encountered when conducting measurements of noise from construction sources. The most significant of these issues are;

- Security of equipment
- Background noise
- Difficulties in anticipating when the construction activity will occur

The first issue pertains to the location of the sound level meter. The receiver should be located at the façade most exposed to the noise source. In many cases, the most exposed façade was in a location which was easily accessible via public thoroughfares, meaning security of the equipment when conducting long term measurements was a major consideration. It can be seen that an external measurement at the most exposed façade minimises measurement uncertainty. However, due to security issues, an indoor long term monitoring was considered which would have to be conducted in a secure location such as a resident's garage. A few attempts of taking such a long-term noise measurement was conducted, however, due to poor quality results, more frequent external measurements were taken into account.

Another issue in the measurement of noise sources from construction was background noise (i.e. any noise source other than that arising from the construction process itself). Many of the measurements were found to be significantly contaminated by noise sources other than construction such as large vehicles passing by the measurement site.

The final issue concerns the times of operation of the source. The schedule of activities on the construction site, despite consultation with the site management, was difficult to anticipate which made the planning of detailed noise measurements problematic. Despite these issues a number of successful measurements have been conducted. Examples are given of the prediction of noise from particular activities / machines on the construction site.

5 Determination of noise exposure for Internal Sources

Internal noise measurements are not covered in this report. A number of problems encountered during conduction of internal measurements were identified in Section 3.2, and as such internal measurements of internal sources were not conducted.

Although, measurements for internal sources did not take place, the uncertainty budget and corresponding procedure were drafted so that if the decision was made to perform them, everything would be prepared.

6 Uncertainty evaluation

Craven & Kerry (2001) describe the methodology of calculating the uncertainties outlined in the following section, of which there are 4 pertinent categories;

- Uncertainties due to measurements of train event occurrences
- Uncertainties due to calculation of exposure to noise based on Calculation of Railway Noise
- Uncertainties due to calculation of internal exposures to noise from construction work
- Uncertainties due to calculation of external exposures to noise from construction work

More detailed explanation of uncertainties was included in technical report 3 "*Calculation of Vibration Exposure*" (Sica, et al., 2011).

6.1 Uncertainties due to measurements of train events occurrence

Relatively few uncertainties are associated with noise measurement for railway traffic noise. The primary issue resulting in the highest level of uncertainty was ground between the source and receiver which was usually found to be composed of a combination of grass and concrete, each of which demonstrate different absorptive and reflective properties. Results from measurements were also influenced by a number of obstacles which varied in terms of size and composition material, resulting in variations of sound energy reflection. Due to regular calibration and sensitivity checks of the measurement equipment, only a small uncertainty value is associated with the receiver signal chain.

Uncertainties	**Notes**	**Lower / Upper limit**	**Distribution**	**Standardised. Uncert.**
Transmission path				
Barriers	At most sites, small obstacles were present	± 0.5 dB(A)	Rect.	0.289
Ground influence	Attenuation due to soft ground and height of source	± 1.5 dB(A)	Rect.	0.750
Receiver				
Sound Level Meter		±1.0 dB(A)	Rect.	0.577
Position of SLM	CRN requirements include position of SLM such that height of the reception point should be located in the range 1.2m above the ground (minimum) to 3.5m above the railhead (maximum); measurements were taken at a height of 1.5m	0.1 dB(A)	Rect.	0.058
COMBINED Uncertainty (root sum of squares)				**0.99 dB(A)**
EXPANDED uncertainty (95% confidence [k = 2])				**1.98 dB(A)**

Table 9 presents uncertainties associated with noise measurements for railway sources.

6.2 Uncertainties from calculation of railway noise

A greater number of uncertainties are expected from calculation of an exposure to noise from railway traffic using predictive methods. Uncertainties mainly arise from assumptions made regarding the number of vehicles that trains are comprised of, the number of trains during the day, evening and night periods (although this was evaluated from control positions monitoring vibration from trains for 24h), the distance between the source and receiver estimated using Google Maps, the ground correction which differs from site to site and the speed of trains travelling through residential areas, where differences in speed are dependant upon on grade, area etc. It is worth noting that ground correction was included in calculation of overall exposure to noise, although difficulties arose due to uncertainties regarding ground composition – whether it was only covered by grass, comprised of concrete slabs or a mix of both. CRN covers this problem although the level of accuracy is dependent upon the routine implemented therein.

The main uncertainties were due to differences in the number of vehicles, which varies from train to train. Trains operating between local stations typically comprise of two or a maximum of three vehicles. Conversely, fast long distance trains typically comprise of five or nine vehicles.

Table 10 presents uncertainties associated with calculation from CRN.

Source of Uncertainty	**Notes**	**Lower / Upper limit**	**Distri-bution**	**Standar-dised. Uncert.**
Source				
Noise emission	Vehicles vary in terms of noise emission – locomotives, EMU, DMU etc.	± 0.8 dB(A)	Rect.	0.462
No. of vehicles	Trains are comprised of a variable number of vehicles between 5 ±3	± 2.5 dB(A)	Rect.	0.83
Velocity	Train speeds are applied considering train speed limits different for different sites; different train (Class 390 and Class 170) can be permitted to different speed within an area whose difference may vary max. by 25 mph (40 kmph)	± 2.0 dB(A)	Rect.	0.67
Transmission path				
Ground correction	Sites vary in terms of ground reflection which requires inclusion in CRN	± 0.4 dB(A)	Rect.	0.231
Distance	25 ±0.2 m	±0.1	Rect.	0.058
COMBINED Uncertainty (root sum of squares)				**2.25 dB(A)**
EXPANDED uncertainty (95% confidence [k = 2])				**5.5 dB(A)**

Table 10 presents uncertainties associated with calculation for railway sources based on Calculation of Railway Noise, 1995.

6.3 Uncertainties from construction - measurements of internal noise exposure

Uncertainties associated with internal exposure calculation are presented in this report, as it was decided not to take measurements due to problems described in Section 3. The most difficult issue found during the limited number of indoor measurements was the very low internal level of external noise sources (those of main interest). With such a low level of sound pressure, it was not considered feasible to obtain data upon which analysis could be performed with sufficient accuracy.

Uncertainties	Notes	Lower / Upper limit	Distribution	Std. Uncert. (dBA)
Source				
Pile dr. eq. (piling)				
Spectral Content	Tonal low freq. component., measurements outside	± 0.2 dB(A)	Rect.	0.013
Height of the source	The noise from piling at 4.5 m above ground level	± 1 dB(A)	Rect.	0.333
Load carrier				
Spectral Content	High level tonal low frequency noise, almost no uncertainties at source	± 0.2 dB(A)	Rect.	0.013
Source character	One source at time of operation (moving along the track line)	± 1 dB(A)	Rect.	0.333
Pile dr. eq. (Vibrating)				
No Spectral comp.		± 1.5 dB(A)	Rect.	0.750
Transmission path				
Piling & Vibrating				
Ground influence	Attenuation due to soft ground and height of source	± 1.5 dB(A)	Rect.	0.750
Barriers	The area of trees and fencing between source and receiver	± 0.5 dB(A)	Rect.	0.083
Position	Both plants were steady	± 0.2 dB(A)	Rect.	0.013
Attenuation due to walls in a property	Due to additional attenuation the measurement introduces extra uncertainty as a sound path was not clear and some high frequency components could not be measured, affecting overall $L_{\text{Aeq(T)}}$	± 1.5 dB(A)	Rect.	0.750
Load carrier				
Position	Position of Load carrier was changing	± 0.5 dB(A)	Rect.	0.083
Receiver				
Mic. orientation	Some standards suggest orienting mic. towards source as opposed to manufacturer recommendations (vertically)	± 1.0 dB(A)	Rect.	0.577
Dynamic range set	Insufficient dynamic range for spectral	± 1.5 dB(A)	Rect.	0.750

	content measurements			
Background noise	Significant level of background noise observed during measurements	± 1.5 dB(A)	Rect.	0.750
Str., grd-borne sound	Negative influence of standing waves, structure and ground-borne sound	± 1.5 dB(A)	Rect.	0.750
COMBINED Uncertainty (root sum of squares)				**2.32 dB(A)**
EXPANDED uncertainty (95% confidence [k = 2])				**4.64 dB(A)**

Table 11 Uncertainty budget evaluation for internal noise exposure from construction work

6.4 Uncertainties from construction - measurements of external noise exposure

Uncertainties associated with outdoor measurements in construction sites were caused by sources of much greater noise level and limited dynamic range of spectral content measurements. The source height of processes such as piling was located at a high level above ground (in excess of 4m). This introduced uncertainties due to differences in propagation of sound at such heights. At construction sites the spectral content was dominated by low and middle frequency components. Resultantly, little or no reflective effects due to small (when compared with the wavelength) objects such as the meter tripod should be included in the calculations.

Due to different positions of sources, a ground reflection component did not always influence the final result. Obstacles such as trees and fences present during measurements could also distort results; however, only small uncertainties were set for their effects.

Additionally, larger uncertainties were set due to the limited dynamic range of the sound level meter when measuring the spectral content of loud sources (exceeding 80 dB(A)). Also, as opposed to measurement for railway sources, uncertainties had to be set due to the significant amount of background noise contaminating the main noise source of construction processes.

Uncertainties due to construction sources are presented in the Table 12 below.

Uncertainties	Notes	Lower / Upper limit	Distribution	Standardised Uncert.
<u>Source</u>				
Pile dr. eq. (piling)				
Spectral Content	Tonal low freq. component., measurements outside	± 0.2 dB(A)	Rect.	0.115
Height of the source	The noise from piling at 4.5 m above ground level	± 1 dB(A)	Rect.	0.577
Load carrier				
Spectral Content	High level tonal low frequency noise, almost no uncertainties at source	± 0.2 dB(A)	Rect.	0.115
Source character	One source at time of operation (moving along the track line)	± 1.0 dB(A)	Rect.	0.577

Pile dr. eq. (Vibrating)				
No Spectral comp.		± 1.5 dB(A)	Rect.	0.866
Transmission path				
Piling & Vibrating				
Ground influence	Attenuation due to soft ground and height of source	± 1.5 dB(A)	Rect.	0.866
Barriers	The area of trees and fencing between source and receiver	± 0.5 dB(A)	Rect.	0.289
Position	Both plants were steady	± 0.2 dB(A)	Rect.	0.115
Load carrier				
Position	Position of load carrier was changing	± 0.5 dB(A)	Rect.	0.289
Receiver				
SLM	Sound level meter calibrated and drift of calibration recorded	± 1.0 dB(A)	Rect.	0.577
Mic. orientation	Some standards suggest orienting the mic towards source, manufacturer recommends setting mic vertically; some uncertainties can be found due to this confusion	± 0.3 dB(A)	Rect.	0.173
Dynamic range set	Dynamic range was insufficient for spectral measurements, and so some overloads occurred	± 1.5 dB(A)	Rect.	0.866
Background noise	Significant level of background noise observed during measurements	± 1.5 dB(A)	Rect.	0.866
COMBINED Uncertainty (root sum of squares)				**1.99 dB(A)**
EXPANDED uncertainty (95% confidence [k = 2])				**3.98 dB(A)**

Table 12 Uncertainty budget evaluation for external noise exposure from construction work

7 Discussion

Noise sources from construction and railway traffic were covered in this report. Although both sources were found to be subjectively annoying, construction work could potentially invoke a much higher negative annoyance response. The details pertaining to associated problems with annoyance can be found in Technical Report 6 "*Determination of exposure response relationship*" (Woodcock et al., 2011) and Technical Report 5 "*Analysis of The Social Survey Findings*" (Condie & Steele, 2011). It was observed that construction activities typically occur within close proximity to residential environments. This could perhaps be the most important aspect influencing upon a resident's reaction. Annoyance can be caused not only by reception of sound or noise, but also by visible effects such as the visual presence of construction work. These factors can also invoke additional adverse effects. As a growing number of construction projects are performed in the vicinity of residential environments, the surrounding community could perhaps find them increasingly annoying. Although primarily due to noise level, other exposures such as vibration, which calculation can be found on Technical Report 3 "*Calculation of vibration exposure*" (Sica et al., 2011), dust, light etc. may also significantly influence upon overall annoyance (Condie & Steele, 2011).

Common noise generators on construction sites were identified, measured and assessed in the calculation of daytime noise exposure from construction-related sources.

For the calculation of noise exposure from construction sources according to BS 5228-1:2009 the methodology applied for measurement of sound pressure level was required for measurements of noise levels of all possible sources which occur during construction work.

BS 5228-1:2009 provides a routine of computation of noise exposure at a distance of 10m between source and reception points respectively. To cover the potential future scenario that additional analysis may be performed, measurements were conducted in three different weightings; A and C, although only A-weighting was applied in the final calculations presented. The choice of A-weighting over other frequency weighting scales was made due to the data required for determination of the noise exposure-response relationship. The pertinent details are described in Technical Report 6 "*Determination of exposure response relationships*" (Woodcock et al., 2011). A-weighting effectively attenuates low and high frequency content in a manner analogous to the human auditory system. Since hearing is less sensitive in these regions, an average person cannot perceive noise of very low or very high frequency as readily. A-weighting was therefore considered to be the most adequate correction to establish the most reliable determination of the exposure-response relationship. On the other hand, in standards such as BS EN ISO 16032:2004 and other relevant international standards, it is sometimes required to conduct C-weighted or un-weighted measurements. One of the papers regarding monitoring of noise of construction work (Ferna et al., 2010) specifies un-weighted frequency measurements. Alternatively, C-weighting is commonly applied in analysis of highly impulsive sounds such as blasting and gun-shots, and in the analysis of the effects of such noises on human hearing impairment (Bee & Swanson, 2007; Pawlaczyk-Łuszczyńska et al., 2004). C-weighting also appears to be more adequate if sound pressure levels exceed 100 dB(A), since the response of the human ear is much flatter when subjected to noise at these levels, and hence more similar to the C-weighting curve.

All aspects were taken into consideration before performing the calculation of daily noise exposure from construction. Since A-weighting is the most representative of human response to noise, it consequently was used over the other weightings.

According to the methodology applied (Section 4) and uncertainties associated with measurement and calculation (Section 5), noise exposures were obtained and used for the determination of exposure-response relationships (Condie & Steele, 2011; Woodcock et al., 2011).

It can be assumed that the methodology for noise measurement was more accurate for the purpose of fulfilling the objectives of this report. One of the biggest challenges found during measurements was to anticipate the schedule of work on construction sites and obtaining data from measurements of as many representative noise sources as possible. Due to its nature, construction work, regardless of the organisation of the site, could not be accurately predicted. As a consequence of this, a small number of processes (such as installation of a drain) were occasionally missed and measurement data could not be obtained. Similarly, measurements have occurred where only part of a period of a specific noise event was covered. Despite these problems, a reasonable amount of data has been obtained in order for the project to predict overall exposures with the fewest uncertainties realistically possible.

Future measurements however may be conducted utilising a much more sophisticated approach with better equipment e.g. as performed by Ballesteros (Ferna et al., 2010). Three suggestions were made as being of greatest importance in such an event;

- A weekly continuous monitoring of all construction work stages for longer periods of time
- Recording of sound during monitoring so that sources could be identified and easily recognised
- Possibility of setting a measurement instrument within the vicinity of a source, or installing a number of instruments such that a construction process will occur within close proximity of at least one

One of the direct consequences of improved methodology is that associated uncertainties from measurement can be significantly reduced due to better identification of a source, decreased influence from background noise and longer period of measurement time ensuring all noise events are recorded.

The results given from construction sites differ slightly (Section 4). The results from South Manchester demonstrate lower levels of noise exposure than those in East Manchester. This could perhaps be explained by the increased distance to facades, (over 100 m), thus limiting reflective effects. The distance itself causes a significant reduction in noise level, although other buildings could have an observable impact on the final results by partially obscuring sources. On the other hand, construction work in East Manchester was essentially situated within residential areas. In fact, a great number of residents were located directly alongside the main road upon which the construction was sited. Direct exposure to the resulting noise would therefore be expected to be much higher than in South Manchester.

Exposure to noise from railway traffic was almost an entirely predictive process, performed according to CRN (Department of Transport, 1995). Similarly to BS 5228-1:2009, CRN provides an accepted methodology for the prediction of noise exposure based on either measured or tabulated noise emissions of particular railway vehicles of interest.

Although a relatively small number of measurements were conducted for railway sources, the application of measured sound exposure levels was deemed to be too complex with respect to the project objectives. Moreover, CRN states that unless a significant reason is mitigated, tabulated data should be chosen over measured data. One of the other reasons for using measured sound exposure levels (L_{AE}) would be that the distance between a rail line and a facade was less than 10m. CRN states that prediction according to its common regular routine cannot guarantee an accurate prediction within a distance of less than 10m. Additionally, CRN requires measurement of a noise source according to a fairly complex procedure which imposes requirements which could not have feasibly been overcome. One of these conditions is the requirement to orientate the microphone of the sound level meter at a height of 4m above a ground level.. Consequently, all measured data were used to validate noise exposures from the prediction as well as from L_{AE} of single events. Values of noise emission are therefore acquired from the relevant tabulated data in CRN.

The level of accuracy of final results depends upon a number of parameters provided in tandem with the calculation (Section 3). Most relevant details are readily available in the public domain from;

- Train operator websites
- Google Maps (Google Inc., 2011)
- National Rail Enquiries website (National Rail Enquiries, 2011)
- Freightliner (for information regarding freight trains) (Freightmaster, 2011)

For the purpose of the project, it was of high importance that information obtained can provide accurate results which are then to be used for estimating the exposure-response relationship (Woodcock et al., 2011). The list of basic information can be classified as followed:

- Distance between a rail line and the most exposed façade

- The number of passenger and freight trains per 24h period
- The average speed of single train along lines situated within residential areas

All the data listed above were applied to the routine based on CRN (Department of Transport, 1995) having made a number of assumptions indicated in Section 3. Other details regarding estimation of railway traffic noise could not be accurately covered and are omitted from the preceding list. The most important detail not accounted for is the topography of the ground, which could not be accurately estimated from available data. Natural barriers such as shielding by cuttings and embankments were not applied.

8 Conclusion

The aim of this technical report is to provide the reader with the process involved in obtaining noise exposures from railway traffic and construction work. Methodology, calculation and results are presented in the previous sections. Calculation of noise exposure for railway traffic was based on CRN (Department of Transport, 1995) and has been estimated from calculation and validated by on-site measurements. Noise exposure for construction sources was also predicted based on BS 5228-1:2009, although noise source data was fully obtained from measurements of noise at two construction sites such as South and East Manchester,

On one hand, exposures from railway traffic were found to be less intensive in level, dominated by low frequency content and reasonably uniformly distributed in terms of energy over time. Railway traffic was also found to occur regularly. Sources are usually screened by obstacles, cuttings, embankments, and generally lie at distances from residences greater than those for construction sources. These contributing factors could go some way towards explaining why annoyance arising from exposure to railway traffic noise is of a lesser magnitude than that induced by construction noise.

On the other hand, exposures from construction work were found to be more highly intensive and within greater proximity to residential areas. The frequency content of such sources lies within the middle frequency range which was much more dominant than found for railway noise sources. Construction noise sources were generally located in positions lacking effective air propagation barriers which might have otherwise reduced residential exposure. These factors could contribute towards an increased annoyance response in comparison with that found for rail traffic.

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PROCEDURE TITLE:		**Procedure for the measurement of environmental noise**			
PROCEDURE NO:		**PP17**			
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APPENDIX A

1 Purpose

This procedure defines the process used by a technical team to measure environmental noise affecting occupants of a residence located near the railway, in order to assess the human response due to the noise.

2 Scope

This procedure applies to environmental noise produced by railway and affects people who are exposed to noise at home.

3 Responsibility

Members of the technical team are responsible for ensuring this procedure is followed when carrying out field measurements.

4 Measurement procedure

4.1 Introduction

The measurement technique is required to assess human exposure to environmental noise produced by railway traffic. The concept of the measurement of noise is divided into two approaches due to circumstances inside a residence: internal and external measurements.

4.2 Calibration of the instrument

This is within responsibility to a technical team that the instrument is checked and calibrated. It is suggested that the instrument is calibrated before the each measurement. If this is not possible, technical team members are encouraged to check the instrument before field work.

4.3 Internal Measurement

The internal measurement process may take place in a in a room which is not significantly influenced by extraneous noise sources.

4.4 External Measurement

The external measurement process takes place when it is necessary to confirm noise levels and when it is not practical to measure internally.

4.5 Mounting the Sound Level Meter

Mount the Sound Level Meter according to section 5.

4.6 Starting the noise measurement process

Turn on the Sound Level Meter (01dB SIP95). Switch the meter to check the batteries by switching the middle button to upper position (only if internal batteries are used – section 6.3). Switch the middle button back to its original position (lower position). If the Sound level Meter is not in "Store" mode, press ESC key a few times until the main menu is visible ("La", "Leq" and "Store" options are visible). Press the "Val" button and choose the "Store" option. Press "Val" button. The Sound Level Metter should be in Store mode. If Sound Level Meter is correctly set up (see section 6) choose Start option and press "Val" button. Press "Val" button again to start the measurement process.

4.7 Internal measurement position

The internal measurement should take place only in a in a room which is not significantly influenced by extraneous noise sources. For more information regarding mounting method in other circumstances, see section 5.1.

The microphone used in the sound level meter is omni-directional and its orientation is not important.

4.8 External measurement position

For noisier residences such as with TV in operation, children or more people in a residence, the external measurement should be taken. Note that mounting method can be different due to weather. For more information, see sections 5.2 and 5.3.

4.9 Mounting Sound Level Meter for internal measurement

Detach the head from the stand. Attach the head to the Sound Level Meter using the thread. Attach the head with Sound Level Meter to the stand.

4.10 Mounting Sound Level Meter for external measurement

See section 4.9 to mount the Sound Level Meter on a stand.

Put the wind shelter on the microphone to avoid measuring turbulence. Note different mounting method due to weather (see section 5).

4.11 Making notes for internal measurements

Put extra information in Note field of the proforma PMV1. Record all information regarding the measurement.

4.12 Making notes for external measurements

Put extra information in Note field of the proforma PMV1. Record all information regarding the measurement.

4.13 Collecting internal measurement sound level meter

Collect sound level meter from a property after measurement of vibration has been done.

4.14 Two or more measurements of vibration

If more than one measurements of vibration takes place, the internal measurement of noise is preferred. Choose and mount the Sound Level Meter in residence least affected by internal noise source contamination.

4.15 On-site data check

Technical team members are encouraged to check if the each measurement has properly been carried out and recorded.

5 Mounting method

Due to weather two different mounting methods take place for external noise measurements.

5.1 Mounting Sound Level Meter for internal measurement

Place the sound level meter near the accelerometer, at 1.5m high from thea floor and rotate the meter so that it lies at an angle of around 45 degrees with a floor. Take measurement according to the section 4.6.

5.2 Mounting Sound Level Meter for external measurement

Choose the most exposed façade and mount the sound level meter on the stand so that the distance between the façade is about 1m and the height between the meter and the ground is 1.5m (see the Figure 25). Note that another mounting method (5.3) is more preferred due to atmospheric conditions.

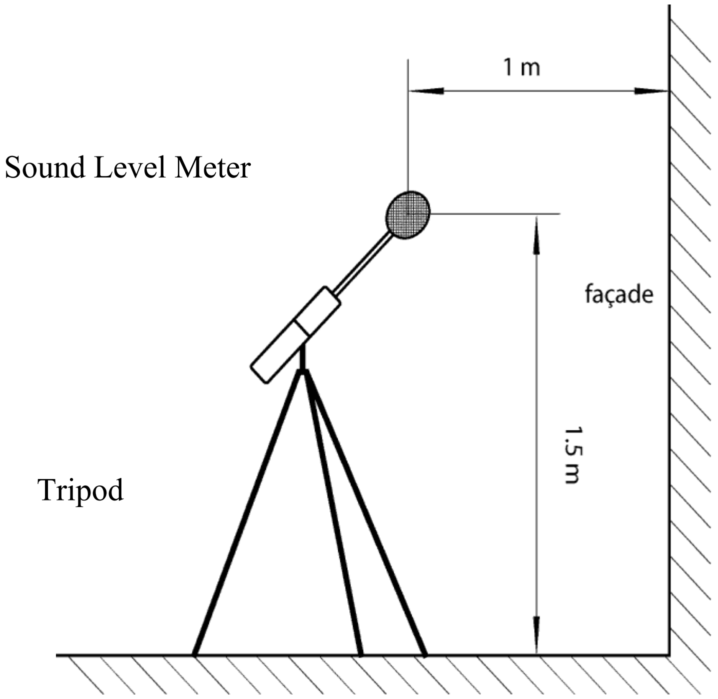

Figure 25. Mounting Sound Level Meter for external measurement

5.3 Mounting Sound Level Meter for external measurement in different atmospheric conditions

This method is preferred the most due to worse atmospheric conditions. For this method one extra extension cable is needed (see Figure 26). Only microphone is attached to a stand and place outside a residence. The sound level meter should be placed under any cover to prevent the sound level meter from getting wet.

Put the microphone within the wind shelter with the little flag such way that the front of the microphone is pointing at the wind shelter (see Figure 26).

Take the tube and put it on the extension cable. Note that the tube has a little cut out on one side. Put the cable through the tube. Screw the tube with the cable down to the wind shelter. Note there is a very fine thread. The microphone should stay in the tube in the right way. Put the extension cable in the cut out of the tube. Screw the cup nut down to the tube. Note the very fine thread. Connect the sound level meter to the microphone in the wind shelter. Note the red spot on both a plug and a socket which need to match.

The Wind shelter with the microphone and the extension cable can be mounted on a stand. Note the wind shelter should not be rotated by 45 degrees but should stay in a stand vertically (see Figure 27).

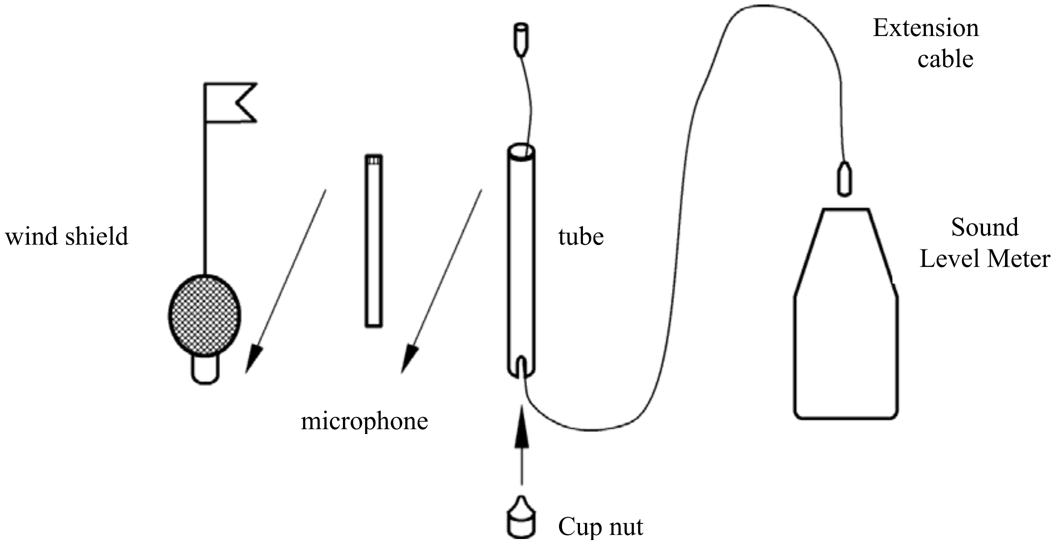

Figure 26. Mounting Sound Level Meter for external measurement during raining.

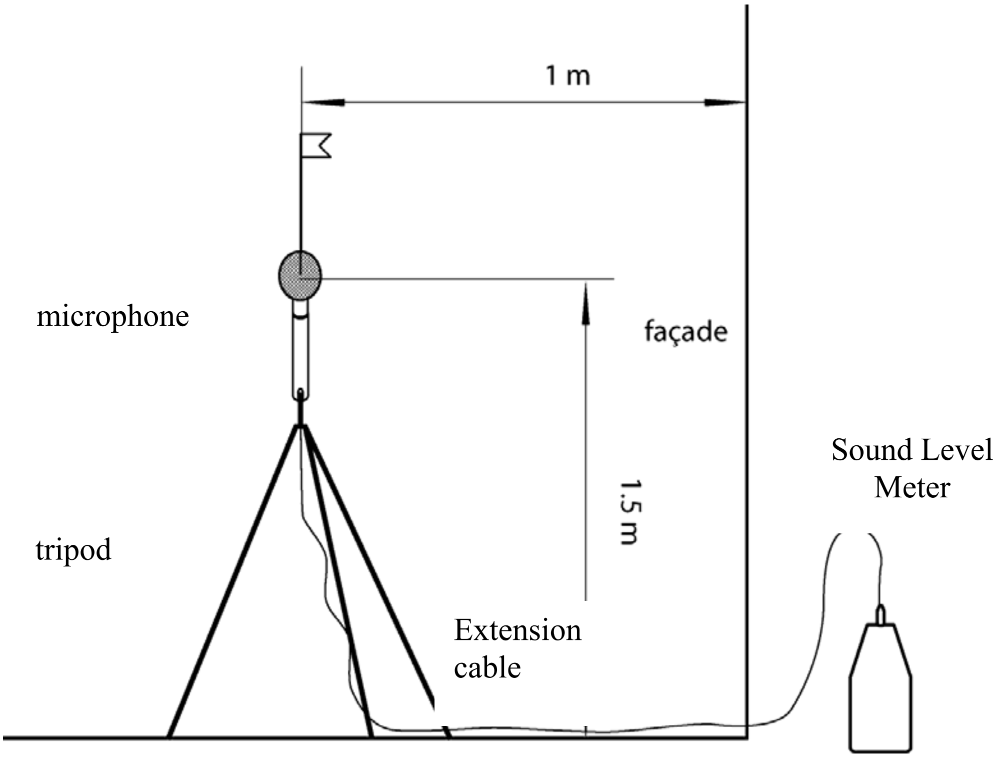

Figure 27. External noise measurement in difficult atmospheric conditions

6 Setting up the Sound Level Meter

The Sound Level Meter should operate only in Store mode when all events can be recorded and analysed later. More information regarding setting up the Sound Level Meter can be found in its manual.

6.1 Changing measuring mode to “Store”

The Sound Level Meter should automatically setup to Store mode. Note the “Store” title at the top of the screen. If Sound Level Meter is in different mode follow these steps.

Press ESC key as many times as main menu is visible. Note three different mode to choose: “Leq”, “La”, “Store”. Press **Val** button. Choose “Store” mode and press **Val** button. The Sound Level Meter should be in Store Mode.

6.2 Setting up Sound Level Meter for proper parameters

The Sound level Meter should take measurements with proper parameters set up such as Leq, T, dB range. These three parameters should be set up as followed

- Leq – 1/3 oct
- T – 1s
- dB range – 20-90 dB

6.3 Power supply for Sound Level Meter

There are couple of methods so that the Sound Level Meter can be suppliedwith power. The manual explains this in detail.

Although Sound Level Meter can operate on common AA batteries, it is strongly recommended that the external power is used, such as the grey batteries used for the Guralps accelerometers.

7 References and Associated Documents:

[1] BS EN ISO 16032: 2004. Acoustics — Measurement of sound pressure level from service equipment in buildings — Engineering method.

[2] Procedure No. PP17. Procedure for the measurement of environmental noise. Quality Manual. University of Salford, Salford, UK.

APPENDIX B

1 Introduction

This document presents instructions that the technical team can follow to conduct environmental noise measurement inside a property directly affected by noise from construction activities. The document is based on the British standard BS EN ISO 16032:2004 [1]. The procedure only conforms to the measurement of noise inside rooms of volume less than 300 m^3.

2 Purpose

The purpose of this document is to suggest the methodology of the environmental noise measurements to assess the human exposure to noise from construction activities.

3 Scope

The procedure applies to environmental noise produced by construction activities which affect residential areas.

4 Responsibility

Members of the technical team are responsible for ensuring the instructions in this document are followed when carrying out field measurements.

5 Measurement Procedure

5.1 Introduction

The measurement technique is required to assess human exposure to environmental noise from construction activities. The procedure regards the noise measurement technique inside a property, however, the simultaneous noise measurements outside a property should also take part due to the possibility of obtaining a better reference.

The noise measurements can be conducted by either a single microphone at three different positions, by advanced multichannel equipment, or by three microphones placed in a room taking all simultaneous measurements.

5.2 Calibration of the instrument

This is within responsibility to a technical team that the instrument is checked and calibrated. It is suggested that the instrument is calibrated before the each measurement. If this is not possible, technical team members are encouraged to check the instrument before field work.

5.3 Internal measurements

The internal measurement is the main subject of this procedure and must be done every time a noise measurement is conducted.

5.4 External measurements

The external measurement is the additional part of this procedure and serves as a reference.

5.5 Mounting the instrumentation

Mount the instrumentation according to section 6.

5.6 Starting noise measurements process

Turn on all instruments which take part. If instruments operate on battery, check if the battery in each instrument is charged sufficiently for the equipment to operate for the required period of time. Synchronise the equipment so that recorded time histories are synchronous for every instrument. If the equipment is to operate along with other instruments (e.g. vibration measurement instrumentation) with recording of time history, synchronise the equipment so that time history recording is exact. Set all the equipment to measure and record L_{eq} with third-octave-band spectrum and time averaging $T = 0.5$s.

5.7 Internal measurement position

The internal measurement is the main subject of this procedure and should be conducted for each noise measurement from construction activities. Choose a room in the property such that one of its walls is the most exposed façade. For the purpose of the noise measurement the room should be nominally quiet. If it is not the case, another room in a property might have to be chosen. For more information regarding mounting method see section 6.

5.8 External measurement position

External measurement takes place outside a property at the most exposed façade. The position of the equipment is explained in section 6.

5.9 Mounting instrumentation for internal measurement

See APPENDIX A

5.10 Mounting instrumentation for external measurement

See APPENDIX A

5.11 Making notes for internal measurement

Put extra information in the “Note” field of the proforma PMV1. Record all information regarding the measurement.

5.12 Making notes for external measurement

Put extra information in the “Note” field of the proforma PMV1. Record all information regarding the measurement.

5.13 Collecting instrumentation after internal measurement

Collect the equipment from a property after the measurement. If the measurement is conducted along with other instruments, collect the equipment after the other measurements are done.

5.14 Collecting instrumentation after external measurement

Collect the equipment from a property after the measurement. If the measurement is conducted along with other instruments collect the equipment after the other measurements are done.

5.15 On-site data check

Technical team members are encouraged to check if the each measurement has properly been carried out and recorded.

6 Mounting method

6.1 Introduction

This section provides information regarding method of mounting and positioning equipment inside and outside the property.

6.2 Mounting instrumentation for internal measurement

The sound pressure level is measured in three microphone positions, one position in a corner of the room and two positions in the reverberant sound field [1]. The measurement should be un-weighted, in third-octave band with time averaging, $T = 0.5$s.

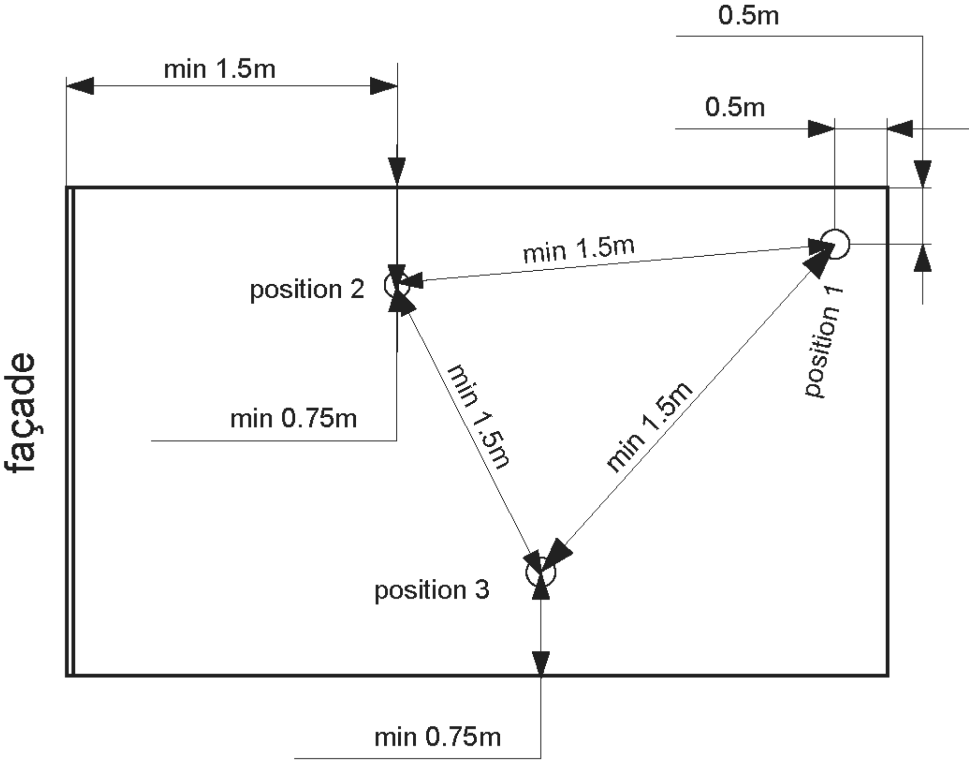

Figure 1. The microphone positions inside a property.

6.2.1 The corner position for the microphone

Search for the corner of the room with the highest C-weighted sound pressure level. The microphone position (no. 1) is preferably 0.5 m from each walls and 0.5 m above the floor. Increase the height to 1m if it is not feasible due to furniture or obstacles or to 1.5m if necessary (see fig. 1). Move away small protruding items that do not affect the sound field, if necessary. The microphone position should be at least 0.2m away from any obstacles. If there is noise source at the corner, e.g. ventilation, choose another corner.

For selection of the corner position, the C-weighted equivalent continuous sound pressure level can be measured directly e.g. by use of a hand held integrating sound level meter.

6.2.2 The microphone positions in reverberant field

Choose two other microphone positions (nos. 2 and 3) in the reverberant field of the room. Keep the minimum distance of 1,5 m between each of the microphone positions 1, 2 and 3. Keep the minimum distance at least 1,5 m from the wall which is the most exposed façade to noise from the construction activities (see fig. 1). If it is possible, keep the distance at least 0.75 m from any surface. If the requirement cannot be fulfilled, decrease the distance to 0.5 m. The height should be between 0.5 m and 1.5 m above the floor.

6.3 Mounting instrumentation for external measurement

Only one microphone has to be used for external measurement. For more details regarding mounting a sound level meter see section 5.2 [2]. For more details regarding setting up a sound level meter see section 6 [2].

Note that in terms of time history the sound level meter should also be synchronised with other equipment placed inside a property.

6.4 Mounting instrumentation for external measurement in different atmospheric conditions

There is a different procedure for mounting instrument outside a property in different atmospheric conditions. For more details see section 5.3 [2].

7 Setting up instrumentation

Instrumentation is to set up according to the manual of a manufacturer.

8 Reference and associated documents

[1] BS EN ISO 16032: 2004. Acoustics — Measurement of sound pressure level from service equipment in buildings — Engineering method.

[2] Procedure No. PP17. Procedure for the measurement of environmental noise. Quality Manual. University of Salford, Salford, UK.