AN INVESTIGATION INTO NOISE EMISSIONS FOLLOWING A RAIL GRINDING CAMPAIGN ON DUBLIN'S LIGHT RAIL SYSTEM

Stephen Byrne

Transport Infrastructure Ireland, Environmental Policy and Compliance Section, Dublin, Ireland
email: Stephen.byrne@tii.ie

Luas is Dublin's modern light rail system. Similar to the majority of urban electrical tramways, the system is relatively quiet when compared to diesel locomotives with similar power output. However, electrical rail systems do produce airborne noise. The principle source is the interaction of the wheels with the rails; termed "rolling noise". Rail roughness, including corrugation, has a substantial influence on rolling noise. To remove rail roughness the rails are ground. In 2012, the acoustic benefits of grinding were investigated on a section of the Luas network. A 10dBA ($L_{Aeq,Tp}$) reduction was achieved at one location with traditional slab track and trams passing at 70km/hr. To further investigate grinding on the network pre- and post-rail grinding, noise measurement surveys were undertaken at eight locations on the network, subject to an initial rail grinding programme in May 2016. A follow up programme was undertaken in early December 2016. Noise surveys were undertaken monthly from January/February 2016 to March 2017 to capture both pre and post-rail grinding noise emissions. Monitoring was undertaken at different track forms (embedded, grass and traditional slab track) with trams passing at different speeds (30–70km/hr). A control location, not subject to rail grinding, was also monitored. This paper details the results at two locations. The grinding campaign was successful with reductions ranging from 4.0dB ($L_{Aeq,Tp}$) at Location 7 and 11.7dB ($L_{Aeq,Tp}$) at Location 2. In specific one third octave bands, reductions of up to 18dB were achieved. However, whilst reductions achieved at Location 7 remain, noise levels at Location 2 are increasing monthly at a rate of approximately 1dBA. It is hypothesised that the corrugation was not completely removed during grinding at Location 2 and remaining roughness is contributing to an increase of roughness levels and associated noise levels.

Keywords: light rail, corrugation, rail grinding

1. Introduction

Railway transport is purported to be the most sustainable transport mode as it consumes less energy and produces less carbon dioxide than any other transport mode (de Vos, 2016). Although evidence suggests that railway noise is less annoying than road traffic and aircraft noise (Schreckenberg et al., 1999), the Green Paper Future Noise Policy of November 1996 by the European Commission states that the "public's main criticism of rail transport is the excessive noise level" (Commission of the European Communities, 1996).

Luas is Dublin's light rail system. Operations commenced in 2004 with the opening of the Luas Green and Red Lines. The system is serviced by Nr.40 Citadis 401 trams which operate on the Red Line and Nr.26 Citadis 402 trams operating on the Green Line. Both the Citadis 401 and 402 trams are four bogied vehicles with three motor bogies and one trailer bogie.

Similar to the majority of urban electrical tramways, Luas is powered the electricity supplied by an overhead catenary system and is relatively quiet when compared to diesel locomotives with similar power output. However, electrical rail systems do produce airborne and/or structure borne noise and vibration which may require abatement. Sources of noise and vibration in the railway system include traction noise from auxiliary equipment fitted to the tram vehicles, curve squeal, joint impact noise and warning signals from trams (chimes, etc.).

The main noise source is the interaction of the wheels with the rails termed rolling noise. Ensuring smooth wheels and rails aids minimal noise generation. Hardy and Jones (2004) report that normally the rail head will exhibit "broadband" surface roughness but at some locations there are periodic wear patterns, known as corrugations, which can have significantly greater amplitudes than the general broadband roughness. Rail corrugation is one of the most serious and expensive problems experienced by transit systems (EU Corrugation Project, 2006). Wheels can also suffer from corrugation. In relation to rail, once a rail has reached an unacceptable level of roughness, the only way of removing the existing corrugation from the rail surface is to grind its surface. It is important to note that grinding is mostly undertaken for reasons of preventing rail defects and fatigue cracks, and not for acoustic reasons (Thompson, 2009). Grinding should focus only on the areas exhibiting significant corrugation or high corrugation growth levels as part of a cost effective corrugation management strategy.

In 2012, the acoustic benefits of rail grinding was investigated on the Luas Red Line at one location. The track form at this location was traditional slab track with trams travelling at a speed of approximately 70 km/hr. The gradient at this location was approximately 4%. A reduction of 10dB ($L_{Aeq,Tp}$) was achieved following the grinding campaign. Upon review of the measured one third octave data, reductions of 10-12dB were achieved between 400 Hertz (Hz) to 630Hz. However, this study was limited and findings were based on only two pre-grinding trackside measurements and three post-grinding measurements. Between January/February 2016 and March 2017 Transport Infrastructure Ireland (TII) undertook a more comprehensive investigation into noise reductions following a rail grinding campaign. The aim of this current study was to determine the acoustic benefits following a rail grinding campaign on the Luas network at eight locations on the network with different track form and tram pass-by speeds. The results at two of these locations are presented and discussed in this paper.

2. Methodology

2.1 Corrugation Survey

Prior to every planned rail grinding campaign, the Infrastructure Maintenance Contractor (IMC) undertakes a corrugation survey of the entire network using a Corrugation Analysis Trolley (CAT). The CAT is supplied with software that enables interpretation and analysis of the recorded data in various ways, including analysis of corrugation wavelength and amplitude. Pre-rail grinding corrugation amplitudes are included in Table 1.

Table 1: Pre-rail grinding corrugation levels at monitoring locations

Monitoring Location	Amplitude
Location 2	198 μm
Location 7	122 μm

2.2 Monitoring Locations

Noise monitoring locations were selected following a desktop review of available historic noise survey data, an onsite review of track form types on the network and a review of the 2015 corrugation survey undertaken by the IMC. Table 2 provides details of track form, tram pass-by design speed, distance to the nearest side rail under consideration and whether the inbound or outbound track was measured at each monitoring location.

Table 2: Noise monitoring location details

Monitoring Location	Track form	Tram pass-by design speed	Distance from nearside rail	Track side
Location 2	Traditional slab	60 km/hr	3.5m	Inbound
Location 7	Embedded	30 km/hr	2.0m	Outbound

2.3 Measurement campaign

The acoustic parameters measured during each monitoring event were (i) $L_{Aeq,Tp}$ (ii) L_{AE} (iii) L_{AFMax} and (iv) linear one third octave frequencies (20Hz – 20kHz). Three tram passes were monitored at each location. All measurements were attended and undertaken in general accordance with ISO 3095:2013. In addition, the following supportive information was noted during each tram by pass (i) tram direction (ii) tram number (iii) estimated tram speed (iv) exposure time and (v) any screeching, braking, acceleration and deceleration characteristics of the tram. During the majority of surveys, a number of events were dismissed due to obvious contamination i.e. either two trams approaching at the same time, by passing road vehicles or neighbourhood activities e.g. mowing of lawns. Noise measurements were made using Class 1 data logging integrating sound level metes fitted with 1:1 and 1:3 Octave Band Filters. A stop watch was used to record the speed of all trams and an anemometer was utilized to measure wind speeds.

2.4 Method for determining wheel and track contributions

When considering noise mitigation options which affect only the track component of noise i.e. rail grinding, it is helpful to identify both the track and wheel contribution to rolling noise. By identifying the relative contribution of each, the acoustic effectiveness of grinding can be better quantified.

Although more precise methods are currently available to determine contributions, historically this relationship has been inferred from simple measurements and the calculation as outlined below has been utilised in this study to determine track and wheel contributions to total rolling noise (IOA, 2010):

- Determine total A-weighted rolling noise (L_{total}): Total rolling noise is the sum of wheel radiated noise and track radiated noise
- Determine the A-weighted level for the spectrum in the frequency range 100 – 1250Hz. This is designated to be the track contribution, L_{track}, to the total rolling noise; and
- Using the following calculation, the wheel contribution can be determined:

$$L_{wheel} = 10\log\left(10^{\frac{L_{total}}{10}} - 10^{\frac{L_{track}}{10}}\right) \quad (1)$$

2.5 Rail grinding programme

In May 2016, the IMC undertook a rail grinding campaign on approximately 10.5km of the network. A grinder fitted with six grinding stones was used for the grinding programme. Results of the pre-grinding corrugation survey were reviewed and locations identified requiring treatment. The number of passes ranged from 2-16. Location 7 was ground as part of the May 2016 campaign.

Following a review of the grinding campaign and review of the pre-grinding corrugation survey, a follow up rail grinding programme was undertaken in December 2016 using the same grinder. Location 2 was ground as part of the December 2016 campaign.

Fig. 1 shows the rail grinder which undertook the December 2016 programme.

Figure 1: Rail grinder on traditional slab track – December 2016.

3. Results

The monitoring results for Location 2 and Location 7 are detailed in Sections 3.1–3.2 respectively.

3.1 Location 2

The broadband parameters, one third frequency analysis and track-wheel contributions are presented in Fig. 2-4.

Between January and November 2016, the L_{AE}, $L_{Aeq,Tp}$ and L_{AFMax} had logarithmic averages of 92.1dB, 81.7dB and 88.3dB respectively (Fig. 2). Following the December 2016 grinding campaign, reductions of 11.2dB, 11.7dB and 12.8dB were achieved respectively with logarithmic averages of 80.9dB (L_{AE}), 70.0dB ($L_{Aeq,Tp}$) and 75.5dB (L_{AFMax}) measured in December 2016. However, between December 2016 and March 2017, all three parameters experienced an increase of approximately 3.0dB. Increasing sound levels are clearly visible within Fig. 2 below.

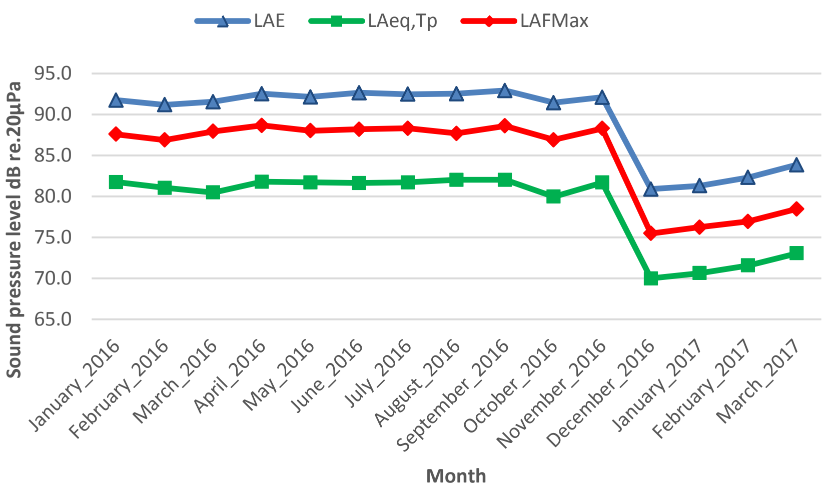

Figure 2: Pre-grinding (Jan-Nov 2016) and post-grinding (Dec-Mar 2017) measured monthly average broadband parameters at Location 2.

The effect of the corrugated track can be clearly seen in Fig. 3 in the form of the broad peak at the frequencies corresponding to the corrugation wavelength i.e. 400 - 500Hz. Following a review of the one third octave data, significant reductions were identified in these two bands following the December 2016 rail grinding campaign when compared against the pre-grinding levels (January-

November 2016) (Fig. 3). Reductions of approximately 16 – 18dB were achieved at both frequencies. Reductions ranging between 4 – 8dB were also achieved between 630 – 1250Hz. However, broadband noise levels were found to increase at a monthly rate of approximately 1.0dB from December 2016 to March 2017. Monthly increases, since December 2016, are clearly visible in 400Hz and 500Hz bands (Fig. 3). In December 2016 levels of 63.2dB (400Hz) and 64.7dB (500Hz) were measured. These levels compare with 68.9dB (+5.7dB) in the 400Hz band and 69.2dB (+4.5dB) in the 500Hz in March 2017.

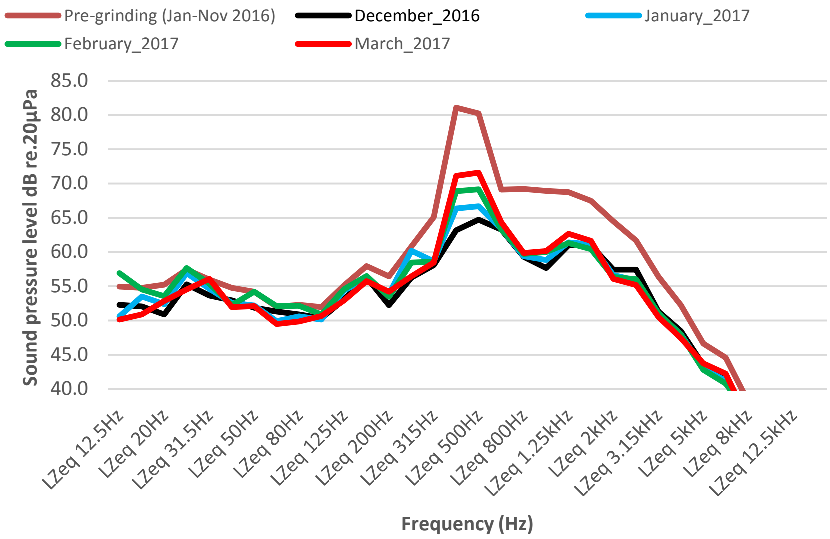

Figure 3: Pre-grinding average (Jan-Nov 2016) and monthly post-grinding (Dec 2016-Mar 2017) one third octave analysis.

Fig. 4 demonstrates that the track noise component dominates the total rolling noise for all measurement events. Between January 2016 and November 2016 the track noise component ranged from 8.5dB to 11dB greater than the wheel noise component. In December 2017, following the grinding campaign, the difference reduced to 2.8dB. However, between January and March 2017 this difference has risen from 4.5dB (January 2017) to 6.2dB (February 2017) to 7.5dB (March 2017).

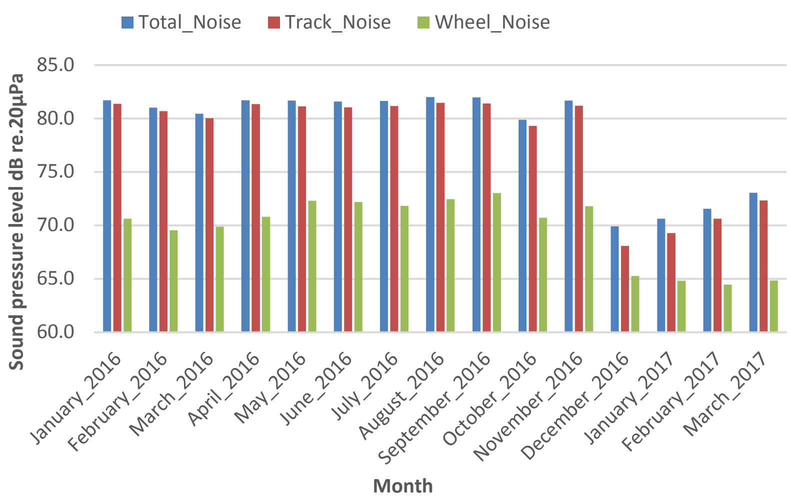

Figure 4: Monthly track and wheel noise contribution to total noise.

3.2 Location 7

The broadband parameters, one third frequency analysis and track-wheel contributions are presented in Fig. 5-7.

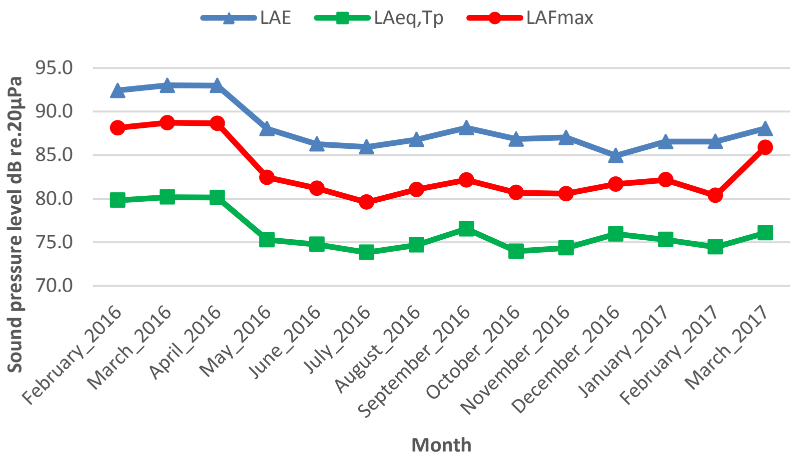

Figure 5: Pre-grinding (Feb-Apr 2016) and post-grinding (May 2016-Mar 2017) measured monthly average broadband parameters at Location 2.

Between February and April 2016, the L_{AE}, $L_{Aeq,Tp}$, and L_{AFMax} had logarithmic averages of 93.0dB, 80.1dB and 88.6dB respectively (Fig. 5). Following the May 2016 grinding campaign, average reductions of 4.9dB, 4.0dB and 2.7dB were achieved respectively with logarithmic averages of 88.1dB (L_{AE}), 76.1dB ($L_{Aeq,Tp}$) and 85.9dB (L_{AFMax}) measured between May 2016 and March 2017. In March 2017 a clear upward spike is evident for the L_{AFMax}. It is hypothesised that this spike is due to wheel related damage e.g. a wheel flat on one of the monitored trams.

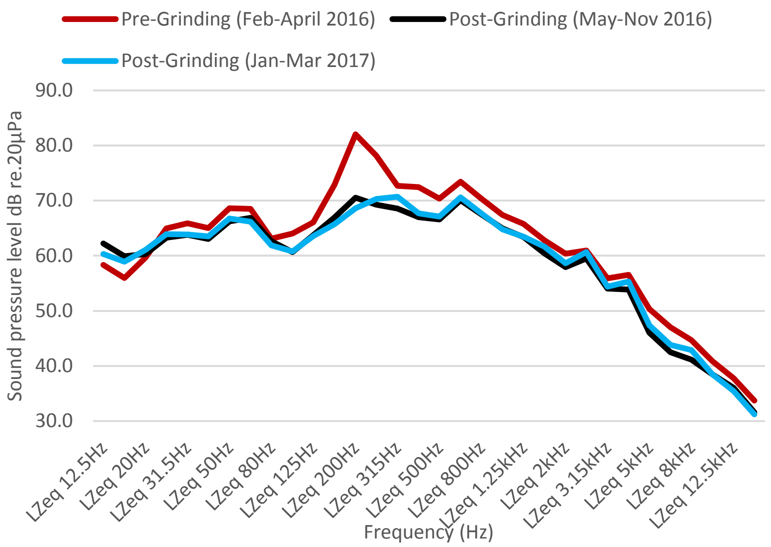

Figure 6: Pre-grinding average (Jan-Apr 2016) and post-grinding (May-Nov 2017 and Dec-Mar 2017) one third octave analysis.

Due to the moderate speed of tram pass bys at this location (30 km/hr) the rolling noise caused by corrugation had a low frequency content i.e. 200Hz. A reduction of approximately 13.5dB was identified in this 200Hz band following the May 2016 rail grinding campaign (Fig. 6). Reductions ranging between 2.0 – 5.5dB were also achieved between 315 – 630Hz. Post-grinding levels have remained relatively constant with no notable increases in any one third octave band.

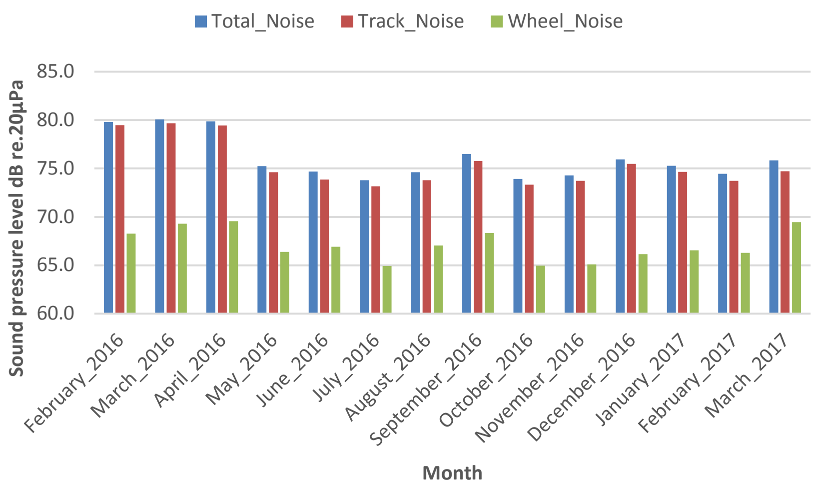

Figure 7: Monthly track and wheel noise contribution to total noise.

Similar to Location 2, a review of Fig. 7 identifies that the track noise component dominates the total rolling noise for all measurement events at Location 7. Between January 2016 and April 2016 the track noise component ranged from 9.9dB to 11.2dB greater than the wheel noise component. Following the grinding campaign, track noise ranged from 6.7dB to 9.3dB greater than the wheel component from May 2016 to February 2017. In March 2017, this dominance reduced to 5.3dB due to the possible wheel flat considered above.

4. Discussion

The results of this study has demonstrated that effective grinding of corrugated rail will result in significant noise reductions. Following the December 2016 grinding campaign broadband reductions of 11.2-12.8dB were achieved at Location 2 with even greater reductions achieved in the frequencies corresponding to the corrugation wavelength i.e. 400 - 500Hz. Such reductions equate to an overall halving of loudness that would be experienced by nearby sensitive receptors. In fact, given the highly tonal dimension of the noise emissions at this location, reductions perceived by the effected populations are even greater. At Location 7, reductions of approximately 4.0-4.9dB were achieved for L_{AE} and $L_{Aeq, Tp}$.

At Location 2, the 2015 pre-rail grinding corrugation study reported a significant amplitude of 198µm. As discussed in Section 3.1, noise emissions levels at Location 2 have been found to be increasing by approximately 1dB per month following the December 2016 grinding campaign. If noise emissions continue to increase at a similar monthly rate, then the pre-rail grinding noise levels will have returned within one year. However, rail surface defects develop in a non-linear way (EU Corrugation Project, 2006). Once a tipping point is reached, rail roughness may develop exponentially and thus, pre-rail grinding noise levels may be experienced in a shorter time frame at Location 2. At Location 7 noise level reductions following the rail grinding campaign have remained relatively constant.

Research reported by the EU Corrugation Project (2006) indicated that existing corrugation is one of the main contributors to the development of further corrugation and the importance of the quality of the grinding process cannot be overstated. Insufficient grinding i.e. remaining roughness, leads to a rapid increase of roughness levels and associated noise levels. It is essential that all corrugation is completely removed after grinding. Based on the acoustic evidence presented in this paper it is hypothesised that all corrugation has not been completely removed at Location 2. Should levels return to November 2016 levels then a further rail grinding campaign will be required. Grinding of the rail on an annual basis will have a significant impact on the maintenance effort and reduce rail lifetime. At Location 7 the 2015 pre-rail grinding corrugation study reported an amplitude of

122µm. Monitoring results over the past 12 months would indicate that the grinding campaign was a success at Location 7.

Rolling noise is the predominant railway noise source, and thus, control methods need to be based on a systems approach (de Vos, 2016). As both track and rolling stock factors contribute to rolling noise, mitigation may need to address both to be effective (Remington, Kurzwell and Towers, 1987). However, in order to achieve rolling noise reduction it is critical to know the relative importance of each factor (Thompson, 2009). For both locations considered within this assessment, and others monitored as part of the overall study, it is evident that both prior to, and post-rail grinding, the dominant noise source is the rail. In recent times, TII in conjunction with our maintenance partners have considered the possibility of introducing mitigation measures for tram wheels. One particular solution considered was the installation of bogie shrouds on the trams. However, this current study has demonstrated that for areas of rail such as those considered within this study, such mitigation measures would result in an imperceptible reduction in noise levels.

5. Recommendations

The results of this study has demonstrated that effective grinding of corrugated rail will result in significant noise reductions. However, to help ensure that achieved roughness and acoustic reductions remain for a sustainable time period, it is recommended that TII, working with our maintenance partners, develop an optimized the rail grinding regime. Such a regime will increase rail life and reduce costs with the added benefit of improving the noise environs for the local population. Recent research and development within the area of rail grinding e.g. the EU INNOTRACK project, should be considered. As part of this optimized regime a comprehensive post-rail grinding corrugation survey should be undertaken within a set timeframe to confirm that grinding has met the desired campaign targets.

REFERENCES

1 de Vos, P. *Railway Noise in Europe. State of the Art*, International Union of Railways UIC-ETF, Paris (2016).

2 Schreckenberg, D., Schuemer-Kohrs, A., Schueme, R., Griefahn, B., Moehler, U. *An interdisciplinary study on railway and road traffic noise: annoyance differences. Forum Acutsicum: 137th meeting of the Acoustical Society of America and the 2nd Convention of the European Acoustics, integrating the 25th German Acoustic DAGA Conference*, Berlin, Germany (1999).

3 European Commission, Future Noise Policy, COM (96) 540, Brussels, November, 1996.

4 Hardy, A. and Jones, R. *Rail and wheel roughness – implications for noise mapping based on the calculation of railway noise procedure*, Department for Environment, Food and Rural Affairs (DEFRA), London, UK (2004).

5 EU Corrugation Project (2006). *Corrugation – wheel rail corrugation in urban transport*. [Online.] available: http://www.coorugation.eu/.html

6 Thompson, D. *Railway Noise and Vibration. Mechanisms, Modelling and Means of Control*, Elsevier, Jordan Hill, Oxford (2009).

7 ISO 3095, 2013. Acoustics, Railway Applications – Measurement of noise emitted by railbound vehicles. International Standards Organisation.

8 Institute of Acoustics Environmental Noise: Prediction, Measurement and Control. Course notes for Diploma in Acoustics and Noise Control. Institute of Acoustics. Hertfordshire (2010).

9 Remington, P,J., Kurzweil, L.G. and Towers, D.A. *Low-frequency noise and vibration from trains*. Ch.16 from Transportation Noise Reference Book, ed. Nelson, P.M. Butterworth & Co.Ltd., 1987.