Rail Vibration Assessment

Stirling Alloa Kincardine Railway Line

Clackmannanshire Council
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Prepared by: [redacted]
Sarah Stranks BSc (Hons) MSc
Graduate Environmental Scientist

Prepared by: [redacted]
Scott Gemmell
Acoustic Technician

Approved by: [redacted]
Gil Van Buuren BMus AMIOA
Regional Director

Rail Vibration Assessment

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225 Bath Street, Glasgow, G2 4GZ
Telephone: 0141 222 6400 Fax: 0141 222 6499 Website: http://www.aecom.com

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1 Introduction

1.1 AECOM was instructed by Clackmannanshire Council to undertake the measurement and assessment of vibration from rail traffic along the Stirling-Alloa-Kincardine (S-A-K) railway line. It is understood that, following the recent re-opening of the line, occupants of nearby dwellings have made complaints with regard to tactile ('feelable') vibration and have raised concerns with regard to building damage.

1.2 A brief description of the S-A-K works relevant to this assessment is given in Section 2. The criteria for assessment are reproduced in Section 3. The rail vibration assessment methodology and results are represented in Section 4 and 5 respectively. Section 6 offers a comparison of the measured results with the Stirling-Alloa-Kincardine Environmental Statement 2003[1]. Recommendations for anti-vibration mitigation from the Environmental Statement and actual mitigation measures incorporated into the design of the S-A-K railway line are provided in Section 7. Finally a summary and conclusions can be found in Section 8.

1.3 Rail vibration measurements were undertaken at four properties in close proximity to the S-A-K railway line in Stirling, Alloa, Clackmannan and Kincardine between Monday 16th July and Saturday 20th July 2009.

1.4 A glossary of vibration terminology is given in Appendix 1.

1.5 Appendix 2 provides additional details on the measurement equipment used.

2 A Brief Description of the Site

2.1 The Stirling-Alloa-Kincardine (S-A-K) rail line comprises approximately 21 km of track between Stirling Station and Longannet Power Station in Kincardine. It provides passenger services from Alloa to Stirling and freight services (including coal transports) to Longannet Power Station.

2.2 The re-opening of the rail line involved reconstructing the line between Stirling and Kincardine along its former route and upgrading the existing railway route between Kincardine and Longannet Power Station. The section of the route from Stirling to Alloa has been re-opened to passenger and freight trains, with a new railway station located at Alloa and a freight only connection through to Kincardine and on to Longannent Power Station.

2.3 The section of the S-A-K rail line where vibration measurements were undertaken is located in areas administered by Clackmannanshire, Stirling and Fife Councils.

3 Criteria for Assessment

3.1 The original recommended vibration assessment criteria within the Environmental Statement[2] was based on guidance contained in BS 6472:1992 and BS 5228:1992. The Environmental Statement assessment criteria is reproduced below:

> ***"Vibration Limits – Nuisance***
>
> *Ground vibrations may cause reactions ranging from 'just perceptible', through 'concern' to 'alarm' and 'discomfort'. The subjective response varies widely and is a function of situation, information, time of day and duration.*
>
> *British Standard BS 6472: 1992 'Guide to evaluation of human exposure to vibration in buildings (1 Hz to 80 Hz) gives base curves of vibrations for minimal adverse comment, and also vibration dose values (VDVs) at which complaints are probable. VDVs may be used to assess the severity of impulsive and intermittent vibration, such as experienced from blasting at quarries or from rail traffic, and steady vibration such as from a busy road or fixed plant.*
>
> *The adoption of the VDV parameter is based on social studies undertaken in the 1980s and early 1990s into human response to vibration. BS 6472 requires that the VDV be determined separate for the 16 hour daytime (07:00-23:00) and 8 hour night-time (23:00-07:00) periods.*
>
> *The VDV is given by the fourth root of the integral of the fourth power of the acceleration after it has been frequency-weighted:*
>
> $$VDV = \left(\int_0^T a^4(t)dt \right)^{0.25}$$
>
> *Where VDV is the vibration dose value (in $ms^{-1.75}$)*
> *a(t) is the frequency-weighted acceleration (ms^{-2})*
> *T is the total period of the day (in seconds) during which vibration may occur*
>
> *The basic procedure is to estimate, or measure, the frequency weighted root mean square (r.m.s.) acceleration levels, and to integrate the several components with respect to time over the day or night-time period so as to compute the VDV. The VDV is measured in each of the three whole-body orthogonal axes and the maximum from the three axes used. Where the vibration conditions are constant or regularly repeated throughout the day and assessment is based on measured data, only one representative period need be measured, and the 16 hour daytime (or 8 hour night-time) overall VDV level may be calculated from the shortened measurement.*

[2] Stirling – Alloa – Kincardine Railway (Route Re-opening) and Linked Improvements (Scotland) Bill – Environmental Statement Volumes 1,2 & 3. – February 2003

The predicted or measured VDV may then be compared to Table 7 in the Appendix of BS6472, reproduced below, to identify the likelihood of complaint:

Table 1[3]: Vibration Dose Values ($ms^{-1.75}$) above which Various Degrees of Adverse Comment may be Expected in Residential Buildings (from BS 6472: 1992)

Location	Low probability of adverse comment	Adverse comment possible	Adverse comment probable
	VDV, $ms^{-1.75}$		
Residential buildings, 16 h day	0.2 to 0.4	0.4 to 0.8	0.8 to 1.6
Residential buildings, 8 h night	0.13	0.26	0.54

For example, between 0.4 and 0.8 $ms^{-1.75}$ adverse comment regarding daytime vibration levels becomes possible, also when the VDV increases above 0.54 $ms^{-1.75}$ at night adverse comment becomes probable. Data included in BS 6472: 1992 may therefore be used to assess the likelihood of adverse comment arising from construction vibration to local residential properties.

Table 2[4]: Impact Descriptor for Residential Vibration

VDV, daytime $ms^{-1.75}$	VDV, night-time $ms^{-1.75}$	Impact Descriptor
Residential buildings 16 h day	**Residential buildings 8 h night**	
<0.2	<0.13	Negligible
0.2 – 0.4	0.13 – 0.26	Slight
0.4 – 0.8	0.26 – 0.54	Moderate
>0.8	>0.54	Severe

Vibration Limits – Building Damage

Buildings are reasonably resilient to ground-borne vibration and vibration-induced damage is rare; there are less than 12 confirmed instances of vibration-induced damage to buildings in the UK over the last 10 years. Vibration-induced damage can arise in different ways, making it difficult to arrive at universal criteria that will adequately and simply indicate damage risk. Damage can occur directly due to high dynamic stresses, due to accelerated ageing or indirectly, when high quasi-static stresses are induced by, for example, soil compaction.

There are currently two British Standards that offer advice on acceptable levels of vibrations in structures. British Standard BS 7385: Part 2: 1993 'Evaluation and measurement for vibration in buildings Part 2. Guide to damage levels from ground-borne vibration' gives guidance on the levels of vibration above which the building structures

[3] Taken from Table 6.2-1 of the Environmental Statement
[4] Taken from Table 6.2-2 of the Environmental Statement

could be damaged. It considers only the direct effect of vibration on a building, since the other mechanisms are different.

For the purposes of BS 7385 damage is classified as cosmetic (formation of hairline cracks), minor (formation of large cracks) or major (damage to structural elements). Guide values given in the Standard are associated with the threshold of cosmetic damage only, usually in wall and/or ceiling lining materials. Since case-history data, taken alone, has so far not provided an adequate basis for identifying thresholds for vibration-induced damage, data using controlled vibration sources within buildings has been established to enable definition of vibration thresholds judged to give a minimal risk of vibration-induced damage.

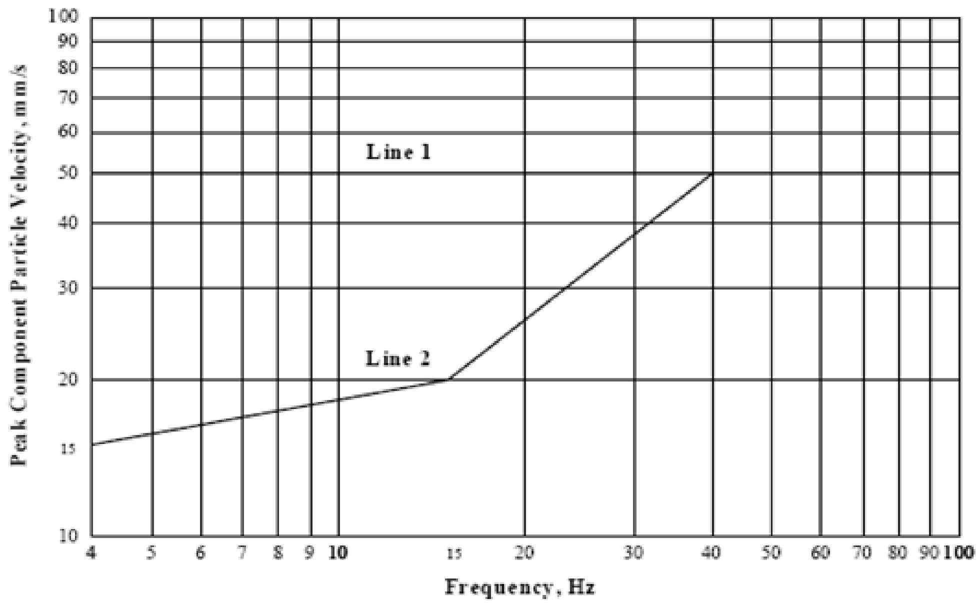
Limits for primarily transient vibration (from a train, for example) above which cosmetic damage could occur are reported in tabular form and graphical form in the Standard and reproduced exactly below:

Table 3[5]: Transient Vibration Guide Values for Cosmetic Damage (from BS 7385: Part 2: 1993)

Transient vibration guide values for cosmetic damage			
Line (*see Figure 1*)	**Type of Building**	**Peak component particle velocity in frequency range of predominant pulse**	
		4 Hz to 15 Hz	**15 Hz and above**
1	Reinforced or framed structures. Industrial and heavy commercial buildings	50 mm/s at 4 Hz and above	
2	Unreinforced or light framed structures Residential or light commercial type buildings	15 mm/s at 4 Hz increasing to 20 mm/s at 15 Hz	20 mm/s at 15 Hz increasing to 50 mm/s at 40 Hz and above
NOTE 1. Values referred to are at the base of the building NOTE 2. For line 2, at frequencies below 4 Hz, a maximum displacement of 0.6 mm (zero to peak) should not be exceeded.			

[5] Taken from Table 6.2-3 of the Environmental Statement

Figure 1[6]: Summary of Damage Theresholds for Transient Vibration on Domestic Structures



The Standard indicates, for example, that for a residential building (line 2) a ppv of greater than 15 mms^{-1} at 4 Hz or greater than 50 mms^{-1} at 40 Hz or above, measured at the base of the building, may be expected to result in cosmetic damage.

Guidance on acceptable vibration levels in structures is also provided in BS 5228: Part 4: 1992 'Code of practice for noise and vibration control applicable to piling operations".

This Standard recommends that a conservative threshold for minor or cosmetic damage should be taken as a peak particle velocity of 10 mms^{-1} for intermittent vibration and 5 mms^{-1} for continuous vibrations to determine whether there is any risk of building damage, particularly from construction works involving piling. It is not clear why there is a discrepancy between the two Standards.

The criteria shown in Table 6.2-4 below (compiled from paragraph 8.4.2, page 24 of BS 5228: Part 4: 1992) can be applied in the case of continuous vibration from piling works.

[6] Taken from Figure 6.2-1 of the Environmental Statement

Table 4[7]: Vibration Limits Relating to Minor or Cosmetic Damage to Buildings

Building Classification	Intermittent Vibration (ppv, mms^{-1})	Continuous Vibration (ppv, mms^{-1})
Residential in generally good repair	10	5
Residential where preliminary survey reveals significant defects	5	2.5
Industrial/commercial – light and flexible structure	20	15
Industrial/commercial – heavy and stiff structure	30	15

BS 5228: 1992 part 4 may therefore be used to assess the likelihood of structural damage arising from vibration associated with construction, both to local residential property and development buildings"[8].

3.2 Subsequent to the publication of the Environmental Statement, updated BS 6472 and BS 5228 have been published and, as such, the AECOM vibration impact assessment has been undertaken using the guidance contained in the newer versions of the British Standards, a brief overview of these follows:.

AECOM Measurement Procedure Criteria

3.3 The vibration assessment was carried out with reference to current recognised British Standards for human response and damage to structures such as buildings. These documents are discussed below.

3.4 BS 6472:2008 *Guide to evaluation of human exposure to vibration in buildings (1-80 Hz)* provides criteria for tactile ('feelable') vibration. Part 1 (*Vibration sources other than blasting*) applies to vibration from rail traffic.

3.5 The criteria *in BS 6472:2008* are specified in terms of a Vibration Dose Value (VDV). This is a measure of the vibration over a period of time. In BS 6472, the time periods are the 16-hour day (07:00-23:00) and 8-hour night (23:00-07:00).

3.6 The VDV is computed on the basis of the time history of the frequency-weighted acceleration. For vibration in the vertical axis, the W_b filter is used to perform the frequency-weighting. For vibration in the orthogonal horizontal axes, the W_d filter is used.

3.7 As a measure, the VDV takes into consideration the greater human sensitivity to vibration magnitude over duration. This means that strong vibrations, even though sporadic, give rise to high VDVs.

3.8 BS 6472 provides guidance on the likelihood of complaints from the occupants of residential buildings. The VDVs corresponding to the complaint thresholds are given in Table 5, below.

[7] Taken from Table 6.2-4 of the Environmental Statement
[8] Stirling - Alloa - Kincardine Railway (Route Re-opening) and Linked Improvements (Scotland) Bill Environmental Statement Volume 3 Supporting Information February 2003. pp141-144

Table 5: Vibration Dose Values for Various Degrees of Adverse Comment

Assessment Period	VDV ($m/s^{1.75}$)		
	Low Probability of Adverse Comment	Adverse Comment Possible	Adverse Comment Probable
Daytime (07:00 to 23:00 hrs)	0.2 to 0.4	0.4 to 0.8	0.8 to 1.6
Night-time (23:00 to 07:00 hrs)	0.1 to 0.2	0.2 to 0.4	0.4 to 0.8

3.9 A 'low probability of adverse comment' does not mean that vibration is imperceptible, as the same VDV could result from a larger number of weaker events or a smaller number of stronger ones.

3.10 Criteria for the redevelopment of the S-A-K line were set out in the Environmental Statement[9]. For tactile vibration, the Environmental Statement refers to BS 6472:1992. This is now superseded by BS 6472:2008.

3.11 In the older version of BS 6472, the W_g filter was used for vertical vibration. With respect to the current W_b filter, this has characteristics which could result in differences of up to a factor of two. The older document also used basi-centric coordinates which were sensitive to human orientation (sitting, standing, lying). The current version of BS 6472 uses geocentric coordinates which do not take such factors into consideration. For these reasons, VDVs measured using the current and superseded versions of BS 6472 are not directly comparable.

3.12 Criteria for the assessment of vibration effects on buildings are given in BS 7385-2:1993 *Evaluation and measurement for vibration in buildings - Part 2: Guide to damage levels from groundborne vibration*.

3.13 BS 7385-2 provides guide values of vibration above which cosmetic damage (such as surface cracks in plaster or brickwork) to buildings could occur. The levels are specified in terms of a Peak Particle Velocity (ppv) in the frequency range 4-250 Hz. These apply to measurement at the base of the building in any of the orthogonal axes. The guide values are summarised in Table 6, below.

Table 6: Vibration Levels above Which Cosmetic Damage to Buildings Could Occur

Type of Building	Peak Component Particle Velocity (ppv) in Frequency Range of Predominant Pulse	
	4 Hz to 15 Hz	15 Hz and above
Reinforced or framed structures Industrial and heavy commercial buildings	50 mm/s at 4 Hz and above	
Unreinforced or light framed structures Residential or light commercial type buildings	15 mm/s at 4 Hz increasing to 20 mm/s at 15 Hz	20 mm/s at 15 Hz increasing to 50 mm/s at 40 Hz and above

[9] Stirling - Alloa - Kincardine Railway (Route Re-opening) and Linked Improvements (Scotland) Bill - Environmental Statement Volumes 1, 2 & 3. – February 2003

3.14 Minor damage is possible at vibration magnitudes which are greater than twice those given in Table 6, and major damage to a building structure can occur at values greater than four times the tabulated values.

3.15 The guide values in Table 6 relate predominantly to transient vibration which does not give rise to resonant responses in structures, and to low-rise buildings. Where the dynamic loading caused by continuous vibration is such as to give rise to dynamic magnification due to resonance, especially at the lower frequencies where lower guide values apply, then the guide values in Table 6 might need to be reduced by up to 50%.

3.16 For the assessment of structural damage to buildings resulting from vibration from construction and operation of the railway line, the Environmental Statement refers to BS 5228:1992 Part 4: *Code of practice for noise and vibration control applicable to piling operations.* This document has now been superseded by BS 5228:2009 Parts 1 and 2.

3.17 The criteria for cosmetic damage in BS 5228:2009 are identical to those in BS 7385.

4 Rail Vibration Measurement Methodology

4.1 Vibration measurements were carried out at selected residential properties in Stirling, Alloa, Clackmannan and Kincardine between 16th and 20th June 2009.

4.2 Automated vibration data logging was carried out for approximately twenty-four hours at each location. The measurements were largely unattended. AECOM staff undertook site observations and made enquiries with residents upon installing and retrieving the measurement equipment.

4.3 Measurements were made of vibration on the ground surface in the gardens of the properties. This was done in favour of measurements within the dwellings, as these would have needed to be vacated in order to control adverse effects from internal vibrations such as footfalls. A conservative semi-empirical model was used to predict in-building levels on the basis of the measured levels. This results in in-building levels that are a factor of 4 higher than ground surface levels. The in-building levels were used to gauge human response.

4.4 The measurement locations were chosen with consideration of both technical and practical issues. The vibration transducer needed to be sufficiently removed from the dwelling in order to be unaffected by vibration sources within it. It also needed to be sufficiently close to the dwelling to account for its ground loading. In placing the equipment, consideration was also given to the risk of tampering, theft and vandalism.

4.5 The vibration transducer was a PCB Piezotronics 393B12 ‘seismic’ accelerometer with a sensitivity of approximately 10 V/g. The most recent calibration certificate for this IEPE-powered device is given in Appendix 2. Using cyanoacrylate adhesive (‘superglue’), the transducer was attached to the horizontal top plate of a 350 mm long steel stake, which was hammered into the ground.

4.6 Measurements were made with a Svantek 948 analyser (serial. no. 9360). This was set to provide frequency-weighted single figures (including VDVs) and spectra in 1/3-octaves. ppvs were obtained from the zero-peak velocity values in the dominant 1/3-octave band below 250 Hz. Measurements were made with an integration time of 15 minutes and 1 second RMS detection. The Svantek was calibrated to the laboratory-measured sensitivity of the accelerometer.

4.7 The Svantek and associated batteries were located in a weather-proof case. The accelerometer was weather-protected using a plastic plant pot, placed upside down and weighted down with a brick or stone. Protection was necessary to minimise the risk of spurious measurements due to wind and moisture ingress. A typical equipment installation (at 76 Causewayhead Road, Stirling) is shown in Figure 2.

4.8 The dynamic response of floor structures in buildings normally results in amplification of groundborne vibration at its natural frequencies. This means that in-building vibration in the vertical axis normally exceeds lateral vibrations by several orders of magnitude. For this reason, vibration measurements were limited to the vertical axis.

Figure 2: Vibration Logging Equipment at 76 Causewayhead Road, Stirling

5 Rail Vibration Measurement Results and Assessment

5.1 76 Causewayhead Road, Stirling

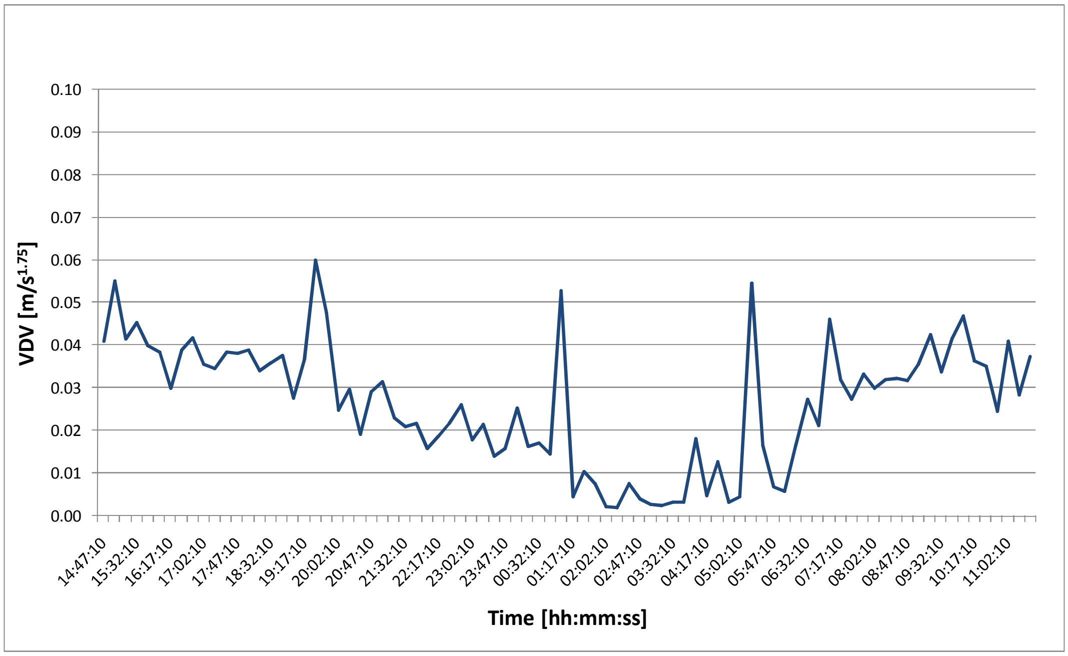
5.1.1 Continuously logged measurements were made from 14:47 on 16 June to 11:47 on 17 June 2009.

5.1.2 The measurement equipment was located approximately 17.5 m from the nearside SAK railway track and approximately 6 m from the south eastern façade of 76 Causewayhead Road. The A9 (Causewayhead Road) lies between the track and the dwelling. Figure 3 illustrates.

Figure 3: Aerial View of Vibration Monitoring Location at 76 Causewayhead Road, Stirling

5.1.3 Figure 4 shows the time history (in 15-minute samples) of the measured VDVs. This trace has a number of notable features. Vibration levels during daytime working hours are reasonably constant. The trend is for levels to reduce during the evening and further during the night. This trend is interrupted by a number of peaks. The peaks are likely to represent the passage of freight trains. The reduction in underlying levels during the night results from the reduction in road traffic on the nearby A9. In summary, it can be said that rail as well as road traffic contributes to the vibration climate during the daytime, but only rail traffic contributes significantly during the night.

Figure 4: Time History of 15-minute VDVs Measured at 76 Causewayhead Road, Stirling



5.1.4 Table 7 summarises the VDVs for the daytime and night-time periods. The measured values are given alongside predicted in-building levels. The predicted VDVs for the daytime period were computed on the basis the measured data using

$$VDV_d = \left(\frac{t_d}{t_1}\right) VDV_1$$

in which t_d is the daytime period of 57600 seconds, t_1 is the measurement period of 46800 seconds and VDV_1 is the measured VDV for that period.

Table 7: Daytime and Night-time VDVs for 76 Causewayhead Road, Stirling

	VDV [m/s$^{1.75}$]	
	16-Hour Day (07:00-23:00)	**8-Hour Night (23:00-07:00)**
Measured	0.101*	0.066
Predicted in dwelling	0.498	0.264

*Measured over a period of 46800 seconds

5.1.5 With reference to the human response criteria in BS 6472, the predicted VDVs for the daytime and night-time periods correspond with the description ‘adverse comment possible’. Complaints from residents can therefore be expected. Of note is that the complaint risk level is the same for the day and night. A general improvement in the risk profile could therefore not be achieved by eliminating night-time rail traffic.

5.1.6 The highest measured ppv was 1.290 mm/s. This level occurred between 19:47 and 20:02, when a freight train is expected to have passed the site. The ppvs corresponding with the two night-time increases in VDV are 0.734 mm/s (01:02-01:17) and 1.076 mm/s (05:17-05:32).

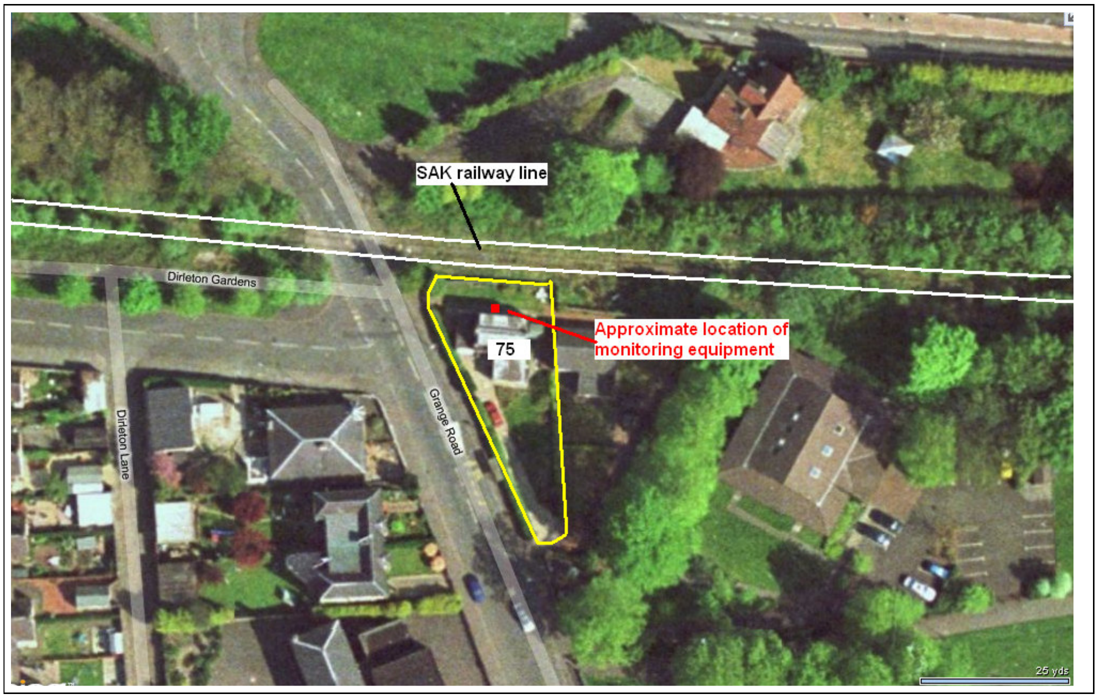
5.1.7 The measured ppvs are well below the criteria in BS 7385. This is even when it is assumed that dynamic magnification occurs, as described in 3.13. It is therefore very unlikely that cosmetic structural damage to the dwelling might result (or might have resulted) from train pass-bys. The likelihood of more profound structural damage is vanishingly low. Residents reported various superficial cracks. It is not uncommon for these to be attributed to vibration where this is perceptible. It must be recognised, however, that cosmetic damage thresholds are around one hundred times higher than perceptibility thresholds. Cosmetic cracks in masonry walls and plaster are often caused by factors unrelated to vibration such as differential settlement, wind loading, thermal movement and humidity.

5.2 75 Grange Road, Alloa

5.2.1 Continuously logged measurements were made from 13:44 on 18 June to 11:14 on 19 June 2009.

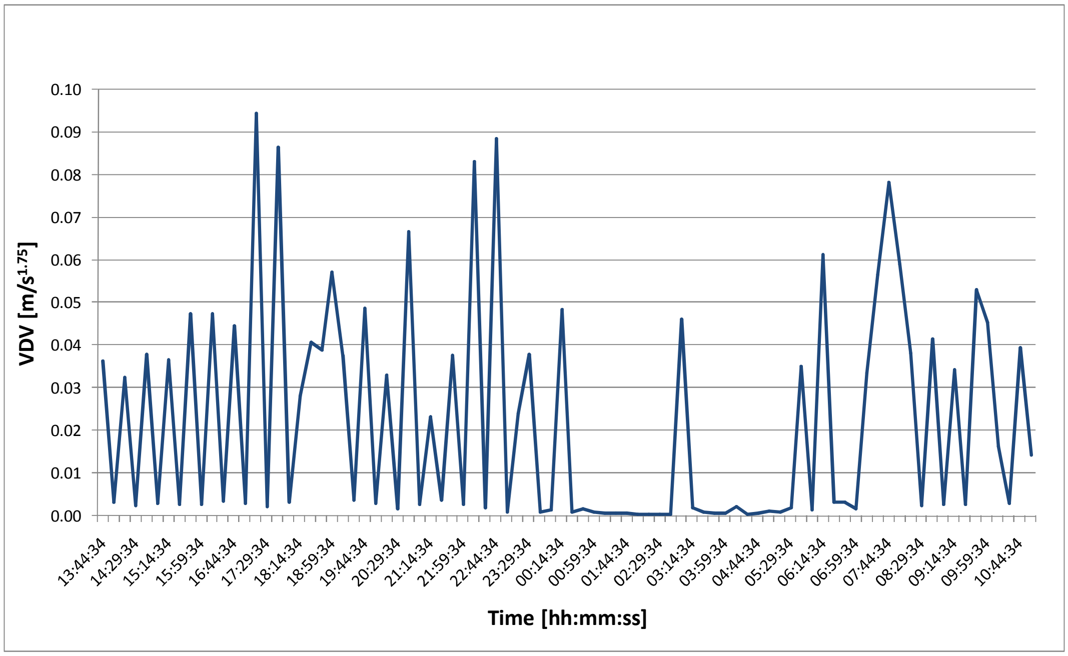
5.2.2 The monitoring location was approximately 6.5 m from the nearside SAK railway track, to the north, and approximately 2 m from the northern façade of 75 Grange Road. Figure 5illustrates.

Figure 5: Aerial View of Vibration Monitoring Location at 75 Grange Road, Alloa



5.2.3 Figure 6 gives the time history of the measured VDVs. A series of regularly spaced peaks rise above a very low background level. The tallest peaks are likely to correspond with freight trains. The half-hourly peaks of lower level are likely to correspond with scheduled passenger services. Other sources of vibration, such as road traffic, are practically insignificant.

Figure 6: Time History of 15-minute VDVs Measured at 75 Grange Road, Alloa



5.2.4 Table 8 summarises the VDVs for the daytime and night-time periods. The measured values are given alongside predicted in-building levels.

Table 8: Daytime and Night-time VDVs for 75 Grange Road, Alloa

	VDV [$m/s^{1.75}$]	
	16-Hour Day (07:00-23:00)	8-Hour Night (23:00-:07:00)
Measured	0.141*	0.073
Predicted in dwelling	0.656	0.291

*Measured over a period of 49500 seconds

5.2.5 With reference to the human response criteria in BS 6472, the predicted VDVs for the day and night-time periods fall within the range corresponding to 'adverse comment possible'. Complaints from residents can therefore be expected. As in the case of Stirling, reduction in night-time rail traffic would not result in an overall improvement in the complaint risk level.

5.2.6 The highest measured ppv was 2.702 mm/s. This level occurred between 17:14 and 17:29 on Thursday 18 June. On Friday 19 June between 00:14 and 00:29, a ppv of 1.387 mm/s was measured.

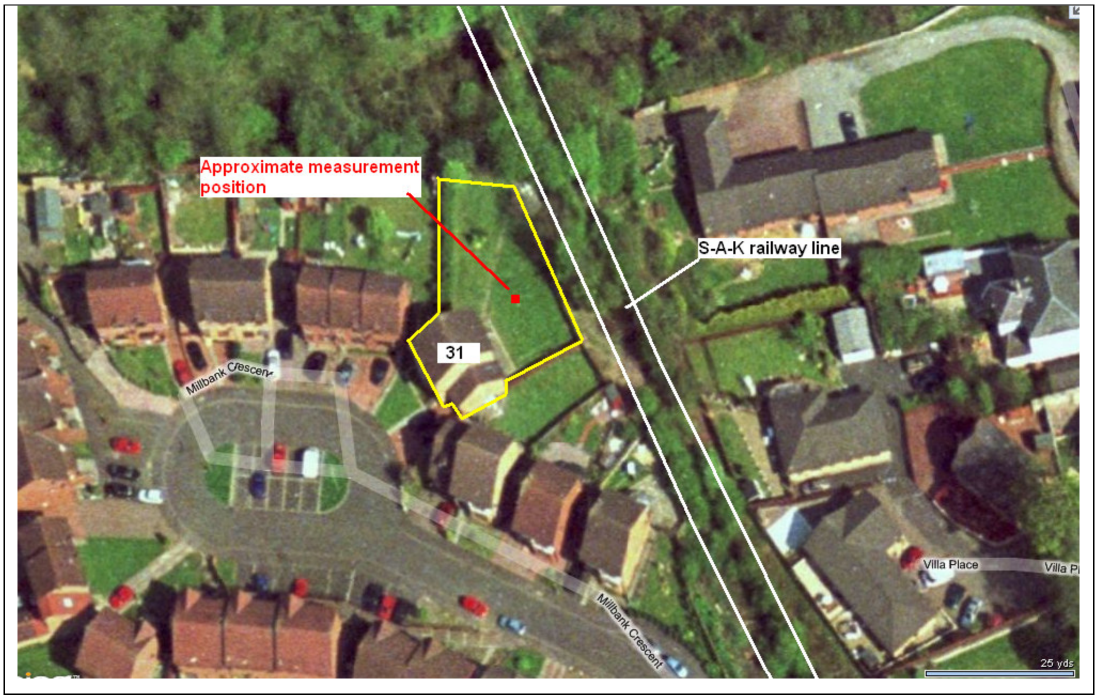
5.2.7 The measured ppvs, though clearly perceptible, are below the criteria in BS 7385. It is therefore unlikely that structural damage to the dwelling, including cosmetic cracking, might result from train pass-bys.

5.3 31 Millbank Crescent, Clackmannan

5.3.1 Continuously logged measurements were made from 13:30 on 17 June to 12:00 on 18 June 2009.

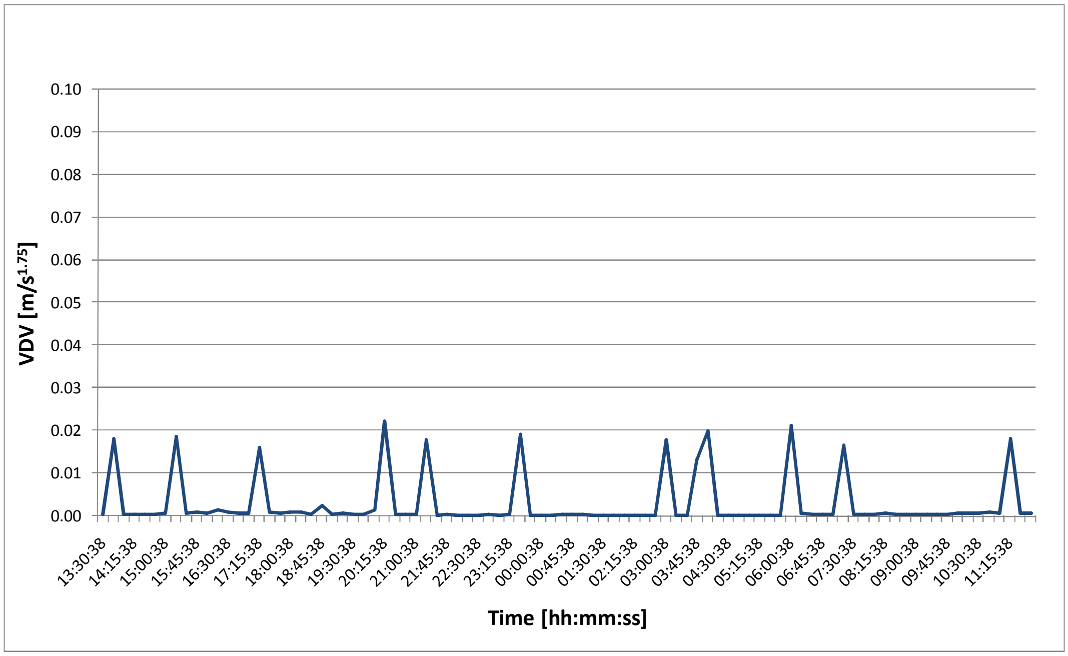
5.3.2 The monitoring location was approximately 15 m from the nearside S-A-K railway track and approximately 6 m from the north-eastern façade of 31 Millbank Crescent, Clackmannan. Figure 7 illustrates.

Figure 7: Aerial View of Vibration Monitoring Location at 31 Millbank Crescent, Clackmannan



5.3.3 Figure 8 gives the time history of the measured VDVs. A series of peaks rise above a very low background level. The peaks almost certainly correspond with train pass-bys. They are similar and relatively widely spaced over time, consistent with freight movements. Other sources of vibration, such as road traffic, are practically insignificant. Comparing Figures 7 with 4 and 6, which are on the same scale, it can be seen that vibration levels at 31 Millbank Crescent are lower than at the dwellings in Stirling and Alloa.

Figure 8: Time History of 15-minute VDVs Measured at 31 Millbank Crescent, Clackmannan



5.3.4 Table 9 summarises the VDVs for the daytime and night-time periods. The measured values are given alongside predicted in-building levels.

Table 9: Daytime and Night-time VDVs for 31 Millbank Crescent, Clackmannan

	VDV [$m/s^{1.75}$]	
	16-Hour Day (07:00-23:00)	8-Hour Night (23:00-:07:00)
Measured	0.030*	0.028
Predicted in dwelling	0.134	0.113

*Measured over a period of 52200 seconds

5.3.5 With reference to the human response criteria in BS 6472, the predicted VDVs for the night-time period fall within the range corresponding to a 'low probability of adverse comment'. Statistically, a minority of people would therefore be expected to complain about vibration from trains. Although individual train pass-bys are 'feelable', vibration during the daytime is below the lowest complaint threshold.

5.3.6 The highest measured ppv was 0.449 mm/s. This level occurred between 11:15 and 11:30 on Thursday 18 June.

5.3.7 The measured ppvs are well below the criteria in BS 7385, even when it is assumed that dynamic magnification occurs as described in 3.13. It is therefore very* unlikely that structural damage to the dwelling, including cosmetic cracking, might result from train pass-bys.

* In this instance the use of the term 'very' is employed to emphasise that this predicted vibration level at the very lower end of the limits as stated within Table 6

5.4 25 Ochil View, Kincardine

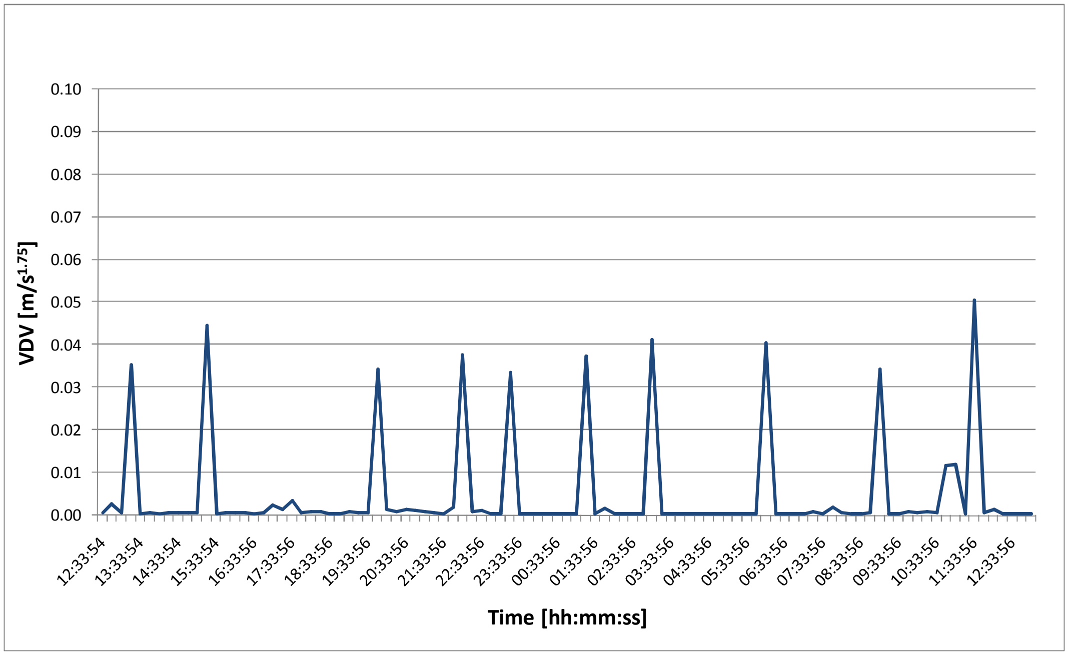
5.4.1 Continuously logged measurements were made from 12:33 on 19 June to 13:18 on 20 June 2009.

5.4.2 The monitoring location was approximately 4 m east of the nearside railway track. The dwelling at 25 Ochil View was then set back a further 2 m. Figure 9 illustrates.

Figure 9: Aerial View of Vibration Monitoring Location at 25 Ochil View, Kincardine

5.4.3 Figure 10 gives the time history of the measured VDVs. A series of peaks rise above a very low background level. As at Clackmannan, the vibration climate is likely to have been dominated by freight trains.

Figure 10: Time History of 15-minute VDVs Measured at 25 Ochil View, Kincardine



5.4.4 Table 10 summarises the VDVs for the daytime and night-time periods. The measured values are given alongside predicted in-building levels.

Table 10: Daytime and Night-time VDVs for 25 Ochil View, Kincardine

	VDV [m/s$^{1.75}$]	
	16-Hour Day (07:00-23:00)	**8-Hour Night (23:00-:07:00)**
Measured	0.064	0.054
Predicted in dwelling	0.256	0.218

5.4.5 With reference to the human response criteria in BS 6472, the predicted VDVs for the night-time period fall within the range corresponding to ‘adverse comment possible’. Complaints from residents can therefore be expected.

5.4.6 The highest measured ppv was 1.410 mm/s. This level occurred between 03:03 and 03:18 on Saturday 20 June.

5.4.7 The measured ppvs, though clearly perceptible, are well below the criteria in BS 7385. Even if dynamic magnification was to occur, structural damage of any kind would be very unlikely.

6 Comparison with Environmental Statement

6.1 The Environmental Statement states that *“The railway line will carry both passenger and freight. However, the greatest vibration impact would arise from coal freight trains serving the Longannet Power Station...There will be a total of 30 railway freight movements (loaded and unloaded) per day travelling at speeds of up to 60 mph, with no regular planned services at night”.*

6.2 *“The highest density of this type of railway traffic currently in operation is found on the line between Gascoigne Wood Colliery and Drax Power station, Yorkshire. To provide an assessment of the likely vibration impact from trains travelling along the S-A-K line vibration measurements were made adjacent to this line in October 2003”.* Table 11 (reproduced from the Environmental Statement[10]) summarises the conclusions of the vibration impact assessment specific to human annoyance.

Table 11: Predicted Daytime VDV Levels for Various Conditions (Without Vibration Mitigation)

Location	VDV ($ms^{-1.75}$) per number of train pass-bys in the 16hr daytime period					
	10 pass-bys	Impact	20 pass-bys	Impact	30 pass-bys	Impact
20 mph, 11m from nearest running rail						
Open Ground	0.11	-	0.12	-	0.14	-
Ground Floor	0.21	2	0.25	2	0.28	2
First Floor	0.42	3	0.50	3	0.55	3
60 mph, 11m from nearest running rail						
Open Ground	0.18	-	0.22	-	0.24	-
Ground Floor	0.36	2	0.43	3	0.48	3
First Floor	0.72	3	0.86	4	0.95	4
60 mph, 20m from nearest running rail						
Open Ground	0.1	-	0.12	-	0.13	-
Ground Floor	0.20	1/2	0.24	2	0.26	2
First Floor	0.40	2/3	0.48	3	0.52	3

Impact -
1 – Less than low probability of adverse comment
2 – low probability of adverse comment
3 – adverse comment possible
4 – adverse comment probable

6.3 From the predicted results of the Environmental Statement assessment, within Table 11, it can be seen that at a distance of 11m from the track, with 30 trains per day trains passing at 60mph the predicted impact is ‘adverse comment possible’ at ground floor level and ‘adverse comment probable’ at first floor level.

[10] Stirling – Alloa – Kincardine Railway (Route Re-opening) and Linked Improvements (Scotland) Bill Environmental Statement Volume 3 Supporting Information February 2003. Table 6.7-3, p.184

6.4 At a distance of 20m from the track, with 30 trains per day passing at 60mph the predicted impact is 'low probability of adverse comment' at ground floor level and 'adverse comment possible' at first floor level.

6.5 These original predicted results approximate well to the predicted at ground floor levels determined from the sampled measured rail vibration results obtained along the S-A-K line in 2009 by AECOM:, only, with the highest predicted vibration levels occurring at 75 Grange Road (within 11m of the track), which fall into the 'adverse comment possible' category.

6.6 The Environmental Statement also states that *"Building damage is assessed using peak particle velocity (ppv) measured 'at the base of the building' to the requirements of BS 7385.*

6.7 *"The worst case open ground peak particle velocity (ppv) recorded at Eggborough was 1.807 mms^{-2} (eastbound loaded, 11 m from track) at 45 kmh. At 60 mph this would be increased to approximately 2.6 mms^{-1} using the velocity correction. At the base of a building (ground floor) this may be doubled to 5.2 mms^{-1}. This figure is well below the limit of 15 mms^{-1} (at 4Hz) specified in BS 7385, and below the limit of 10 mms^{-1} for intermittent vibration specified in BS 5228: Part 4: 1992. Use of anti-vibration measures incorporated into the design of the track where it passes close to residential property would further reduce the predicted ppv.*

6.8 *Consequently it is unlikely that vibration from passage of fully loaded freight trains travelling at 60 mph would give rise to even cosmetic damage at properties as close as 11m from the nearest running rail"[11].*

6.9 These predictions also approximate well to the findings obtained from the 2009 sample rail vibration measurements locations along the S-A-K railway line, in terms of building damage, i.e., it is considered that even if dynamic magnification was to occur, structural damage of any kind would be very unlikely and therefore the risk of cosmetic cracking would be negligible.

6.10 The SAK railway line has a route speed of 60mph between Stirling and Alloa, Speeds on the section between Alloa and Longannet have subsequently been reduced from the original proposals, to 30mph.

[11] Stirling - Alloa - Kincardine Railway (Route Re-opening) and Linked Improvements (Scotland) Bill Environmental Statement Volume 3 Supporting Information February 2003. p. 185

7 Mitigation

7.1 In terms of mitigation of possible rail vibration from the S-A-K railway line, the Environmental Statement makes general recommendations for anti-vibration measures that could be incorporated into the design of the track, where the track is in close proximity (stated as being within 20m of the track), to residential housing:

> *"Anti-vibration measures (ballast mats, baseplate pads, floating slab track etc.) incorporated into the design of the SAK track in sections where it is in close proximity to residential property would reduce transmitted vibration by a factor of up to 10, depending on local conditions. A reduction of only approximately 20% is required to reduce daytime VDV at ground floors at 11m from the track at 60 mph to 'low probability of adverse comment'"[11].*

7.2 Information supplied by the SAK Project Team on the actual mitigation measures incorporated into the design of the S-A-K railway line is reproduced below:

1. *"Insulated Block Joints (IBJ)*

   The SAK project specifically installed a modern type of insulated block joint on the route-6 hole, shop glued out with the S&C. This type of IBJ has no gap (ie. it is tight jointed) for thermal expansion and the lack of gap reduces the noise and vibration which is associated with IBJ's which do have gaps. This type of IBJ is known to fit better and tighter on the ground, which facilitates less movement than the standard site made Joints which are not as strong, and tend to dip over time and with traffic, increasing noise and vibration.

   The 6-hole Shop Glued is the best available and the use of this type of joint reduces movement and therefore noise it will also require less maintenance in future.

2. *The ballast depth used in the construction of the SAK project, was above the minimum design depths stated in the approved detailed design. Greater ballast depth disperses vibration before it reaches the track formation.*

3. *The Switch and Crossings were designed specifically with concrete bearers which assist in the transitions between steel and concrete sleepers. This reduces the vibration impacts associated with less smooth transition between Switch and Crossings and steel sleepers used on other projects.*

4. *The route is formed of Continuous Weld Rail to reduce noise and vibration impacts of the train passing over section breaks in the rail. The only section which is jointed track is on the Forth Viaduct from Stirling North, and this was required to meet the radius curve at this point.*

5. *Geogrid, which is used for track stabilisation, was installed on SAK will assists in reducing impacts of noise and vibration"[12].*

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[12] Information supplied by SAK Project Team - *Design Features Specific to the SAK Permanent Way which aim to minimise Noise and Vibration Impacts.*

8 Conclusions

8.1 AECOM was instructed by Clackmannanshire Council to undertake vibration measurements and an assessment of vibration from rail traffic along the Stirling-Alloa-Kincardine (S-A-K) railway line.

8.2 Vibration measurements were undertaken at four properties in close proximity to the recently re-opened S-A-K railway line. It is understood that occupants of these properties, in Stirling, Alloa, Clackmannan and Kincardine, have made complaints with regard to vibration. The measured vibration levels have been gauged against criteria for human perception (BS 6472) and building damage (BS 7385).

8.3 At the properties in Stirling and Alloa, vibration levels were found to correspond with the description ‘adverse comment possible’. Residential complaints can therefore be said to align reasonably with this objective assessment. Levels corresponding to ‘adverse comment possible’ were found to occur during both the day and night-time periods. This suggests that the underlying cause of the complaints is not primarily related to the hours of operation of the line, but the inherent magnitude of vibration it generates.

8.4 At the property in Kincardine, vibration levels equate to ‘adverse comment possible’ only for the night-time period. Again, complaints from residents align reasonably with this objective assessment. If the extent of night-time use was to be suitably reduced, diurnal vibration levels would equate to levels corresponding with a ‘low probability of adverse comment’. This suggests that hours of operation, rather than inherent magnitude, are the underlying cause of the complaints.

8.5 At the property in Clackmannan, vibration levels correspond with a ‘low probability of adverse comment’. Residential complaints can therefore be said not to align well with objective assessment.

8.6 These predicted rail vibration levels approximate well to the predicted rail vibration levels, without mitigation, for human perception (BS 6472) as stated within the Environmental Statement (see Section 6).

8.7 In terms of mitigation the Environmental Statement recommended ballast mats, baseplate pads, floating slab track etc. be incorporated into the design of the SAK track in sections where it is in close proximity to residential properties (i.e. within 20m).

8.8 At all dwellings, measured levels of vibration are well below those that could give rise to cosmetic building damage such as cracks in plaster or brickwork. The risk of more profound structural damage due to train vibration, including cosmetic cracking, is vanishingly low.

8.9 These findings also approximate well to the Environmental Statement which states that *"it is unlikely that vibration from [sic] passage of fully loaded freight trains travelling at 60 mph would give rise to even cosmetic damage at properties as close as 11m from the nearest running rail"*[11].

Appendix 1: Vibration Terminology

Peak Particle Velocity PPV	The highest instantaneous zero-peak vibration velocity measured over a certain period of time
Vibration Dose Value VDV	The preferred measure for assessing the extent to which a human being has been exposed to a particular source of vibration over a given period of time

Appendix 2: Instrument Certification

~ *Calibration Certificate* ~

Per ISO 16063-21

Model Number: 393B12

Serial Number: 21382

Description: ICP® Accelerometer

Method: Back-to-Back Comparison

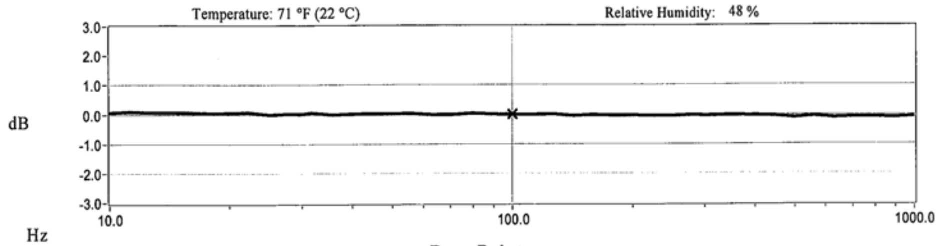
Manufacturer: PCB

ACS-1, ACS-4

Calibration Data

Sensitivity @ 100.0 Hz	**9.89**	**V/g**	Output Bias	11.6	VDC
	(1.009	**V/m/s²)**	Transverse Sensitivity	4.9	%
Discharge Time Constant	5.5	seconds	Resonant Frequency	13.3	kHz

Sensitivity Plot



Data Points

Frequency (Hz)	Dev. (%)	Frequency (Hz)	Dev. (%)
10.0	0.7	300.0	-0.5
15.0	0.8	500.0	-1.3
30.0	0.2	1000.0	-0.9
50.0	0.3		
REF. FREQ.	0.0		

Mounting Surface: Stainless Steel w/Silicone Grease Coating Fastener: Stud Mount Fixture Orientation: Vertical

Acceleration Level (rms)[1]: 0.100 g (0.981 m/s²)[2]

[1]The acceleration level may be limited by shaker displacement at low frequencies. If the listed level cannot be obtained, the calibration system uses the following formula to set the vibration amplitude; Acceleration Level (g) = 0.010 x (freq)².

[2]The gravitational constant used for calculations by the calibration system is; 1 g = 9.80665 m/s².

Condition of Unit

As Found: In Tolerance, No Adjustment Necessary

As Left: In Tolerance

Notes

1. Calibration is NIST Traceable thru Project 822/277342 and PTB Traceable thru Project 1254.
2. This certificate shall not be reproduced, except in full, without written approval from PCB Piezotronics, Inc.
3. Calibration is performed in compliance with ISO 9001, ISO 10012-1, ANSI/NCSL Z540-1-1994 and ISO 17025.
4. See Manufacturer's Specification Sheet for a detailed listing of performance specifications.
5. Measurement uncertainty (95% confidence level with coverage factor of 2) for frequency ranges tested during calibration are as follows: 5-9 Hz; +/- 2.0%, 10-99 Hz; +/- 1.5%, 100-1999 Hz; +/- 1.0%, 2-10 kHz; +/- 2.5%.

Technician: Chuck DiMaggio *CD* Date: 12/26/08

ACCREDITED

CALIBRATION CERT #1862.01

PCB PIEZOTRONICS INC.

VIBRATION DIVISION

3425 Walden Avenue · Depew, NY 14043

TEL: 888-684-0013 · FAX: 716-685-3886 · www.pcb.com

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