3 Criteria for Assessment

3.1 The original vibration assessment criteria within the Environmental Statement[1] were based on guidance contained in BS 6472:1992, BS 7385: 1993 and BS 5228:1992. The Environmental Statement assessment criteria are reproduced below:

"Vibration Limits – Building Damage

Buildings are reasonably resilient to ground-borne vibration and vibration-induced damage s 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 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.

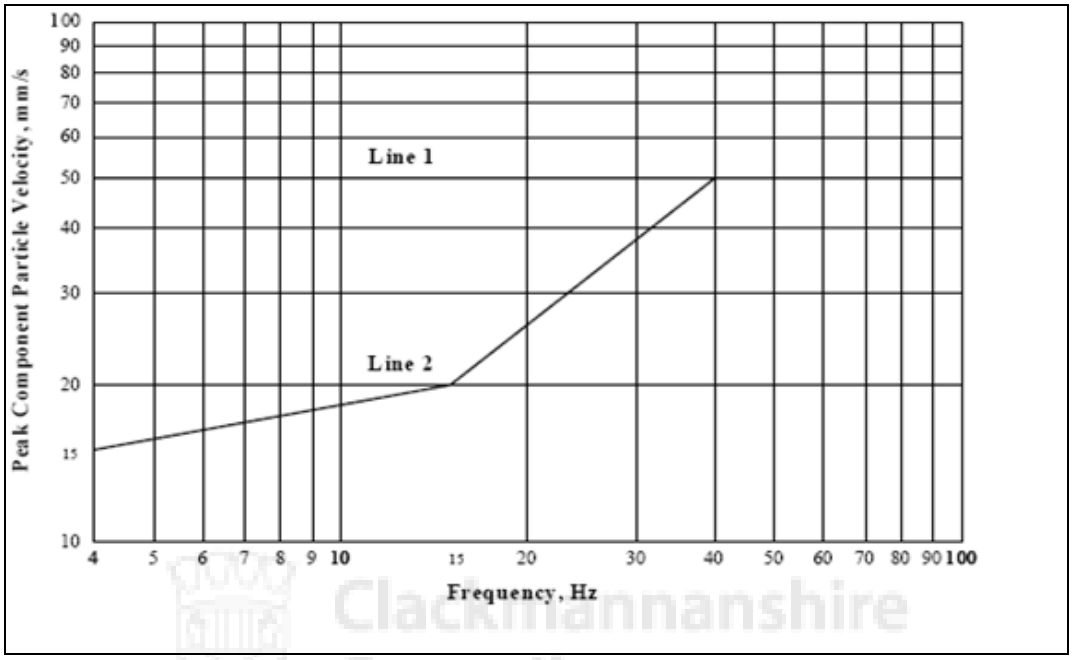
Limits for primarily transient vibration (from a train, for example) above which cosmetic damage could occur are reported in tabular form and graphical form in the Standard and reproduced exactly below:

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

Table 1[2]: 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 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 15Hz 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 0.6mm (zero to peak) should not be exceeded			

Figure 1[3]: Summary of Damage Thresholds for Transient Vibration on Domestic Structures



The Standard indicates, for example, that for a residential building (line 2) a PPV of greater than 15mms^{-1} at 4Hz 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 5mms^{-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.

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

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.

Table 2[4]: 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"[5].

3.2 Subsequent to the publication of the Environmental Statement an updated version of BS 5228 has been issued. The present assessment has been undertaken in accordance with this latest version of the standard, for which further details are provided below.

AECOM Measurement Procedure Criteria

3.3 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*.

3.4 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 3, below (this table is the same as that shown in Table 1, which is reproduced from BS 7385 -2: 1993).

Table 3: 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

3.5 Minor damage is possible at vibration magnitudes which are greater than twice those given in Table 3, and major damage to a building structure can occur at values greater than four times the tabulated values.

3.6 The guide values in Table 3 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

[4] Taken from Table 6.2 – 4 of the Environmental Statement

[5] Stirling - Alloa - Kincardine Railway (Route Re-opening) and Linked Improvements (Scotland) Bill Environmental Statement Volume 3 Supporting Information February 2003. pp141-144

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 3 might need to be reduced by up to 50%.

3.7 With regard to 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 Past 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.

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

3.9 It must be borne in mind that the threshold criteria for cosmetic/structural damage to buildings are normally orders of magnitude higher than those for human perception ('feelability').

4 Rail Vibration Measurement Methodology

4.1 Vibration measurements were carried out at selected residential properties in Causewayhead, Alloa, Clackmannan, Kennet and Kincardine between 17 and 25 November 2010.

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 measurements 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.

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. The distance from the transducer to the railway line also needed to approximate the distance from the railway to the perimeter of the dwelling. In placing the equipment, consideration was also given to the risk of tampering, theft and vandalism.

4.5 The vibration transducer was a Vibrock tri-axial geophone with a frequency range of 4.5 Hz to 250 Hz. The amplitude range of the device is 0.1 – 200 mm/s. The transducer is packaged in a small aluminium case with three adjustable spiked feet and a spirit level.

4.6 The vibration transducer was located on the top plate of a 350 mm long metal spike, which was fully hammered into the ground. The transducer was coupled by gravity to the spike and levelled horizontally.

4.7 Measurements were made with three Vibrock V901 Digital Seismographs, each deployed at a different measurement location. The units were set to provide PPVs with an integration time of 30 seconds. The measured PPV is the zero-peak value in any one of the orthogonal measurement axes x, y or z. With train vibration, vertical forces normally dominate and the PPV therefore normally results from excitation in the z-axis. The measured PPV is not a vector sum.

4.8 Previous measurements undertaken by AECOM indicated PPVs up to approximately 3 mm/s. The full scale deflection of the Vibrock instruments was therefore set to 10 mm/s. This means that vibration levels that exceed 10 mm/s will be limited to a value of 10 mm/s.

4.9 The Vibrock was calibrated to the laboratory-measured sensitivity of the geophone. Calibration certificates for the analysers are given in Appendix 2.

4.10 The Vibrock and associated batteries were located in a weather-proof case. The geophone was weather-protected using a plastic plant pot, placed upside down and weighted down with a brick. Protection was necessary to minimise the risk of spurious measurements due to wind and rain ingress.

4.11 The measurement system has a noise floor equivalent to a PPV of approximately 0.3 mm/s. This means that the system is not capable of measuring vibration levels below this value. Since the assessment criteria are several orders of magnitude above the noise floor, this limitation is of no practical consequence.