APPENDIX - NOISE AND VIBRATION

Noise Terminology, Guidance and Criteria

Terminology

Between the quietest audible sound and the loudest tolerable sound there is a million to one ratio in sound pressure (measured in pascals, Pa). Because of this wide range a noise level scale based on logarithms is used in noise measurement called the decibel (dB) scale. Audibility of sound covers a range of approximately 0 to 140 dB.

The human ear system does not respond uniformly to sound across the detectable frequency range and consequently instrumentation used to measure noise is weighted to represent the performance of the ear. This is known as the 'A weighting' and annotated as dB(A).

The following table lists the sound pressure level in dB(A) for common situations.

Table 1: Noise Levels for Common Situations.

Typical Noise Level, dB(A)	***Example***
0	Threshold of hearing
30	Rural area at night, still air
40	Public library Refrigerator humming at 2m
50	Quiet office, no machinery Boiling kettle at 0.5m
60	Normal conversation
70	Telephone ringing at 2m Vacuum cleaner at 3m
80	General factory noise level
90	Heavy goods vehicle from pavement Powered lawnmower, operator's ear
100	Pneumatic drill at 5m
120	Discotheque - 1m in front of loudspeaker
140	Threshold of pain

The noise level at a measurement point is rarely steady, even in rural areas, and varies over a range dependent upon the effects of local noise sources. Close to a busy motorway, the noise level may vary over a range of 5 dB(A), whereas in a suburban area this may increase up to 40 dB(A) and more due to the multitude of noise sources in such areas (cars, dogs, aircraft etc.) and their variable operation. Furthermore, the range of night-time noise levels will often be smaller and the levels significantly reduced compared to daytime levels. When considering environmental noise, it is necessary to consider how to quantify the existing noise (the ambient noise) to account for these second to second variations.

A parameter that is widely accepted as reflecting human perception of the ambient noise is the background noise level, L_{A90}. This is the noise level exceeded for 90% of the measurement period and generally reflects the noise level in the lulls between individual noise events. Over a one hour period, the L_{A90} will be the noise level exceeded for 54 minutes.

The equivalent continuous A-weighted sound pressure level, L_{Aeq}, is the single number that represents the total sound energy measured over that period. L_{Aeq} is the sound level of a notionally steady sound having the same energy as a fluctuating sound over a specified measurement period. It is commonly used to express the energy level from individual sources that vary in level over their operational cycle.

The index adopted by the Government to assess traffic noise is $L_{A10,18h}$, which is the arithmetic mean of the noise levels exceeded for 10% of the time in each of the eighteen 1-hour periods between 06:00 and 24:00. A reasonably good correlation has been shown to exist between this index and residents' perception of traffic noise over a wide range of exposures.

The $L_{Amax,fast}$ measurement parameter is the maximum instantaneous sound pressure level attained during the measurement period (30 seconds, 5 minutes etc.), measured on the 'fast' response setting of the sound level meter. It is generally used to assess potential for night-time sleep disturbance.

Most environmental noise measurements and assessments are undertaken for 'free-field', away from any existing reflecting surfaces (other than the ground). However, it is sometimes necessary to consider noise levels immediately external to a façade when considering the impact on residents inside properties and this requires the addition of 3 dB(A) to the predicted (or measured) free-field level due to noise reflection from the façade. The assessment of road traffic noise, for example, is based on a predicted (or measured) façade noise level (using the L_{A10} statistical parameter).

Human subjects, under laboratory conditions, are generally only capable of noticing changes in steady levels of no less than 3 dB(A). It is generally accepted that a change of 10 dB(A) in an overall, steady noise level is perceived to the human ear as a doubling (or halving) of the noise level. (These findings do not necessarily apply to transient or non-steady noise sources such as changes in noise due to changes in road traffic flow, or intermittent noise sources).

Guidelines and Criteria

World Health Organisation

The World Health Organisation's (WHO) 'Guidelines for Community Noise' (Reference 1) reports, for external environmental noise levels, that;

During the daytime, few people are seriously annoyed by activities with L_{Aeq} levels below 55 dB; or moderately annoyed with L_{Aeq} levels below 50 dB. Sound pressure levels during the evening and night should be 5-10 dB lower than during the day…

Table 4.1 of the WHO guidelines recommends environmental daytime limits of 55 dB L_{Aeq} or less over the 16 hour daytime period (07.00-23.00) "*to avoid minimal serious annoyance*", and 50 dB L_{Aeq} "*to avoid minimal moderate annoyance*".

For night-time noise sources the WHO guidelines recommend a night-time (23.00-07.00) 8-hour noise level of 45 dB L_{Aeq} "*outside bedroom windows*" (for a reasonably steady noise source) and on a sleep disturbance basis the WHO guidelines state in Section 3.3 that:

"For a good sleep, it is believed that indoor sound pressure levels should not exceed approximately 45 dB L_{Amax} more than 10-15 times per night……"

This recommended limit specific to sleep disturbance is confirmed in Table 5 of British Standard BS 8233: 1999 'Sound Insulation and noise reduction for buildings' (Reference 2) where it states for noise levels internal to a bedroom that:

"For a reasonable standard in bedrooms at night, individual noise events (measured with F time-weighting) should not normally exceed 45 dB $L_{Amax.}$"

The WHO guidelines recommends a limit of level of 60 dB $L_{Amax,(fast)}$ for *"Outside bedrooms, sleep disturbance, window open, outdoor values"*. This follows since an open window will provide an insertion loss of approximately 15 dB(A) and consequently a noise level of 60 dB $L_{Amax,fast}$ external to an open bedroom window would lead to a resulting internal level of 45 dB $L_{Amax,fast}$.

Construction Noise – Impacts to Residential Areas

Noise levels generated by construction activities are regulated by guidelines and subject to local authority control. Advice is contained within British Standard BS 5228: 1997 *'Noise and vibration control on construction and open sites'* (Reference 3). It contains a database on the noise emission from individual items of equipment and activities and routines to predict noise from demolition and construction methods to identified receptors. The prediction method gives guidance on the effects of different types of ground, barrier attenuation and how to assess the impact of fixed and mobile plant.

As far back as 1963 the Wilson Committee report on noise recommended that outside the windows of the nearest occupied dwelling in an urban area a noise level of 75 dB(A), and in suburban or rural areas a level of 70 dB(A), should not be exceeded by noise from construction work. This serves as a useful general guideline, but is not sufficiently definite on whether the quoted levels can be exceeded at all, or whether a construction project taking one or two days should be treated differently from one taking one or two years or even longer.

Minerals Planning Guidance 11: '*The Control of Noise at Surface Mineral Workings*' (MPG 11) (Reference 4) was issued by the Department of the Environment and the Welsh Office in April 1993 and provides advice to developers and planning authorities for noise generated at noise-sensitive developments due to mineral extraction, open cast coal extraction and landfill operations. MPG 11 identifies periods where it may be permissible to modify normal noise limits where high noise levels generated during site preparation and restoration work (at minerals extraction sites etc.) are unavoidable. In paragraphs 42 and 61 MPG 11 states:

"It will often be necessary to raise the noise limits to allow temporary but exceptionally noisy phases …..It is suggested that 70 dB $L_{Aeq,1h}$ (free field) for periods of up to 8 weeks in a year should be considered to facilitate this…"

Operational Noise – Fixed Plant

British Standard BS 4142: 1997 'Method for rating noise affecting mixed residential and industrial areas' (Reference 5) details a method of rating the acceptability of increases in the background noise level L_{A90} at noise-sensitive developments affected by noise from fixed plant (pumps, generators, HVAC units etc.) at existing or proposed fixed developments, such as superstores, factories and commercial/industrial units.

In Section 8 "Assessing the noise for complaint purposes" it is stated that an excess above the existing background noise level L_{A90} of up to 5 dB(A) due to noise from fixed plant at a new development is of 'marginal significance'. This has been interpreted, since the introduction of the Standard in 1967, that a 5 dB(A) excess due to new, fixed plant noise source is, in general, acceptable. An excess of between 5 and 10 dB(A) falls into an intermediate area where local conditions may affect the likelihood of complaints arising (such as local feeling towards the development, the nature of the development etc.). An excess above the background noise level of greater than 10 dB(A) can be taken as a positive indication that complaints are likely.

The ambient background noise varies throughout the day and night-time periods. For new plant that may operate on a 24-hour basis it is appropriate to measure the reasonable minimum ambient background noise level (which would normally occur in the early hours of the morning) at nearest noise-sensitive receptors (normally local residential property) and to use this value for comparison against the predicted noise level from the new plant. If it can be shown that the noise from the proposed new fixed plant would not exceed the minimum background ambient noise level by more than 5 dB(A) for the quietest period of the night then it follows that the 5 dB(A) excess will be met at all other times throughout a 24 hour period.

Operational Noise – Rail Traffic

When addressing the potential impact of a new road or railway noise source the indication is that it is necessary to consider the short-term impact (upon opening of the scheme) and the long -term impact (when residents are familiar with the scheme).

GoMMMS (Guidance on the Methodology for Multi-Modal Studies, DETR, 2000) Volume 2, Chapter 4, Section 4.3 (Reference 6) offers guidance on how to assess the noise impacts of multi-modal plans and strategies. The approach is based on the difference in the estimated population annoyed by noise between the do-minimum and do-something scenarios. A long-term annoyance response curve for rail traffic noise is given in Table 4.2 of GoMMMS, an extract of which is reproduced below, Table 2.

Table 2: Extract From Table 4.2, GoMMMS

Rail Noise ($L_{Aeq,18h}$)	% Annoyed (long term)
55	11
60	16
65	22
70	30

GoMMMS has now been replaced by the Scottish Transport Appraisal Guidance (STAG) with Sub-Objective 6.11 relating to noise and vibration (Reference 7). The assessment methodology is identical to that set out in GoMMMS.

It is known that for an abrupt increase in noise levels associated with the opening of a new road (or railway) there may be an immediate community response to the change in noise level, which is known to diminish with time due to familiarisation. The above table represents the percentage of an exposed population 'annoyed' by long-term railway noise but there is no evidence in the literature proposing a short-term annoyance rating (due to lack of social studies, although such information exists for road schemes). Short-term annoyance may best be described by the actual increase in noise levels due to the scheme above the ambient noise levels, whereas long-term annoyance may best be described in terms of the overall final noise level due to the scheme (regardless of the pre-existing ambient noise level).

GoMMMS states:

" *it is important to be aware that at low noise levels (over large distances), the annoyance response function is uncertain and prediction becomes inaccurate. Consequently, it is recommended that a cut-off noise level is introduced to the appraisal, below which only a small percentage of the population would be annoyed…… PPG24* [PAN56 in Scotland] *and WHO suggest an onset of community noise impact at daytime 55 dB* $L_{Aeq,18h}$. *This corresponds to a population annoyed from road and rail traffic of about 10%. Therefore 55 dB* $L_{Aeq,18h}$ *is the recommended cut-off level to use in estimating the total population annoyed*."

Draft Guidelines For Noise Impact Assessment, issued by the Institute of Acoustics and the Institute of Environmental Management and Assessment (Reference 8) aim to "*set good practice standards for the scope, content and methodology of noise impact assessments*". Chapter 7 of that document gives guidance on assessment and how judgements on the severity of impacts can be made. It also presents an example table, reproduced below as Table 3, categorizing the significance of noise changes. It is stressed that this table is merely an example and should not be used to define the description of the noise change in an assessment, and that the words used to describe the impact should be determined by the assessor for the particular scheme under consideration.

Table 3: Example of Categorizing the Significance of the Basic Noise Change

Noise Change, dB(A)	Category
< 1	No impact
1 < 3	Slight impact
3 < 5	Moderate impact
5 < 10	Substantial impact
> 10	Severe impact

Based on the guidance given in GoMMMS and the IOA/IEMA document and with reference to short-term and long-term changes in the ambient noise due to the scheme, a significance table has been developed as shown in Table 4, and this is the basis of the assessment for railway noise used in this assessment:

Table 4: Categorization of the Significance of Noise Impact

Façade $L_{Aeq,18h}$ (from railway)	Increase in L_{Aeq} (day, evening, night periods)			
	1 < 3	3 < 5	5 < 10	>10
< 55	negligible	negligible	minor	minor
55 < 60	negligible	minor	moderate	moderate
60 < 65	negligible	minor	moderate	substantial
> 65	negligible	moderate	substantial	substantial

An additional criterion, to reflect the likelihood of night-time sleep disturbance, is $L_{Amax,fast}$ the maximum pass-by noise level, as discussed in the WHO Guidelines previously referenced. Noise impacts are identified where levels of 60 dB $L_{Amax,fast}$ and above occur at the bedroom window façade of a residential property during the period 23:00-07:00 (assuming an open bedroom window; a higher façade level would be appropriate with a closed bedroom window).

Under certain circumstances, occupiers of dwellings affected by rail traffic noise from a new or additional railway may be entitled to noise insulation treatment (acoustic glazing and acoustic ventilation to habitable rooms) under the Railway Noise Insulation Regulations (Reference 9) (although these have not been adopted in to Scotland). These circumstances are defined by three conditions, which have to be met;

1. the combined expected maximum rail traffic noise level (i.e. the relevant noise level from the new or altered railway) must not be less than the specified noise levels (68 dB $L_{Aeq,18h}$ daytime (06:00-24:00) and 63 dB $L_{Aeq,6h}$ night-time (24:00-06:00).

2. the relevant noise level is at least 1.0 dB(A) more than the prevailing noise level.

3. the contribution to the increase in the relevant noise level from the new or altered railway must be at least 1.0 dB(A).

Noise from the railway shall be assessed at a reception point located 1 metre outward of the external side of a qualifying window. The railway flows to be used in the calculation shall be the noisiest expected traffic flows occurring during the specified day and night periods within a period of 15 years after opening the system.

It is not necessary to meet the criteria for both day and night-time operation. For example, certain windows may qualify for noise insulation for proposed daytime operation even if night-time proposed operation does not meet the criteria.

Operational Noise – Road Traffic

The Design Manual for Road and Bridges (DMRB) Volume 11 Section 3 Part 7 '*Traffic Noise and Vibration*', 1994 (Reference 10) provides a method of evaluating both the immediate and long term impact of abrupt changes in the 18-hour traffic flow (06:00-24:00) in terms of the effects on people and, principally, occupiers of residential property. (Statistical data in DMRB cannot be applied to assessment of railway noise due to different public perception of road and rail sources).

Individuals vary widely in their response to traffic noise, although the average or community response from a large number of people to the same level of traffic noise is fairly stable. Consequently, a community average degree of annoyance can be related to the $L_{10,18h}$ traffic noise level. The annoyance caused by the existing traffic noise and the predicted future traffic noise is calculated, therefore enabling the increase, or decrease in the percentage of people likely to be annoyed to be determined.

DMRB requires that an assessment is undertaken where an increase in a road traffic flow of 25% or greater is predicted (equivalent to an increase or decrease in road traffic noise of approximately 1 dB(A)), implying that road traffic flow increases of up to 25% offer no significant impact in environmental noise terms.

New Housing

Planning Advice Note: PAN56 (Reference 11) includes advice to local authorities on the use of their planning powers to minimise the adverse impact of noise when determining planning applications for new residential development. It introduces the concept of noise exposure categories (NECs) for residential development, encourages their use and recommends appropriate levels for exposure to different sources of noise. A brief discussion of the most relevant paragraphs of PAN56 follows.

Paragraphs 50 and 51 of PAN56 state:

"This advice note suggests the use of Noise Exposure Categories (NECs)to help planning authorities determine applications for residential development on sites subjected to noise from road, rail air and mixed transportation noise……"

"For category A sites, noise is unlikely to be a determining factor, while for category D sites refusal of planning permission is likely to be the most appropriate solution. Categories B and C deal with situations where noise mitigation measures may make development acceptable…. "

PAN56 recommends adopting a 16-hour daytime period of 07.00-23.00 and an 8 hour night-time period of 23.00-07.00. Annex 1 of PAN56 sets out the approach in more detail and puts forward a range of recommended values.

In summary, if the daytime noise level across a proposed residential development site is below 55 dB $L_{Aeq,16h}$ (corresponding to Noise Exposure Category A) and night-time below 45 dB $L_{Aeq,8h}$ then PAN56 states that:

"Noise need not be considered as a determining factor in granting planning permission, although the noise level at the high end of the category should not be regarded as a desirable level".

For areas falling into Noise Exposure Category B or C (day or night-time) it is possible to address moderate or high levels of environmental noise by specifying noise reduction measures such as acoustic barriers to reduce noise levels to gardens and facades, and acoustic ventilation and glazing to reduce internally-transmitted noise.

Vibration Terminology, Guidance and Criteria

Basic Theory

When an object is in contact with a vibrating surface it is displaced about its reference (stationary) position. Displacement (in mm) is therefore one parameter that can be used to describe the magnitude of a vibration. For sinusoidal signals, displacement, velocity (ms^{-1}) and acceleration (ms^{-2}) amplitudes are related mathematically by a function of frequency and time. If phase is neglected, as is always the case when making time-average measurements, then the velocity can be obtained by dividing the acceleration signal by a factor proportional to frequency (measured in Hertz, Hz) and the displacement can be obtained by dividing the acceleration signal by a factor proportional to the square of frequency. Modern electronic integrating meters are capable of providing a wide range of measurement parameters during any single vibration measurement.

For a complex acceleration signal giving rise to a complicated time history, there are several additional quantities, which can be used to describe this vibration:

1. the peak value is the maximum instantaneous acceleration measured during the measurement time, T. It is a useful indicator of the magnitude of short duration shocks;

2. the root mean square value (rms) is obtained by taking the square root of the mean of the sum of the squares of the instantaneous acceleration measured during the total measurement time, T;

3. the peak particle velocity (ppv) is the maximum instantaneous velocity of a particle at a point during a given time interval.

Perception

Human perception to vibration is of the order of $0.15mms^{-1}$ to $0.3mms^{-1}$ ppv, in the frequency range 0.1 Hz to 1500 Hz. (The lowest note, ‘A’, on a full size piano keyboard has a fundamental frequency of 28 Hz). However, the human body is not equally sensitive to all frequencies of vibration and weighting curves to reflect the frequency dependency of the body have been developed and are contained within ISO Standards. Those frequencies to which the human body is most sensitive are given a much heavier weighting than those at frequencies to which the body is less sensitive. This weighting gives a good correlation between the measured vibration level and the subjective feeling or impact produced by the vibration.

The weightings can be incorporated into modern vibration meters, thus enabling measurement of vibration levels that correspond to human perception. Those vibrations occurring between 1-80 Hz are of particular interest when measuring exposure to whole-body vibration.

Sensitivity to mechanical vibration is also known to be dependent on the direction of excitation and also the human body responds differently when standing (longitudinal) compared to when lying down (lateral). Whole-body vibrations are consequently measured in the directions of an orthogonal co-ordinate system having its origins at the location of the heart.

Day and night-time assessment routines differ to account for longitudinal (daytime) body position and lateral (night-time) body position.

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)* (Reference 12) 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:

$$VDV = \int_0^T a^4(t)dt)^{0.25}$$

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.

The predicted or measured VDV may then be compared to Table 7 in the Appendix of BS 6472, reproduced below, to identify the likelihood of complaint:

Table 5 (from BS 6472: 1992) Vibration Dose Values ($ms^{-1.75}$) above which various degrees of adverse comment may be expected in residential buildings.

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.

Based on the above table, the following impact descriptor has been concluded, Table 6:

Table 6: 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'* (Reference 13) 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:

Table 7:Transient Vibration Guide Values for Cosmetic Damage (from BS 7385: Part 2: 1993).

Transient vibration guide values for cosmetic damage			
Line *(see Figure)*	**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.			

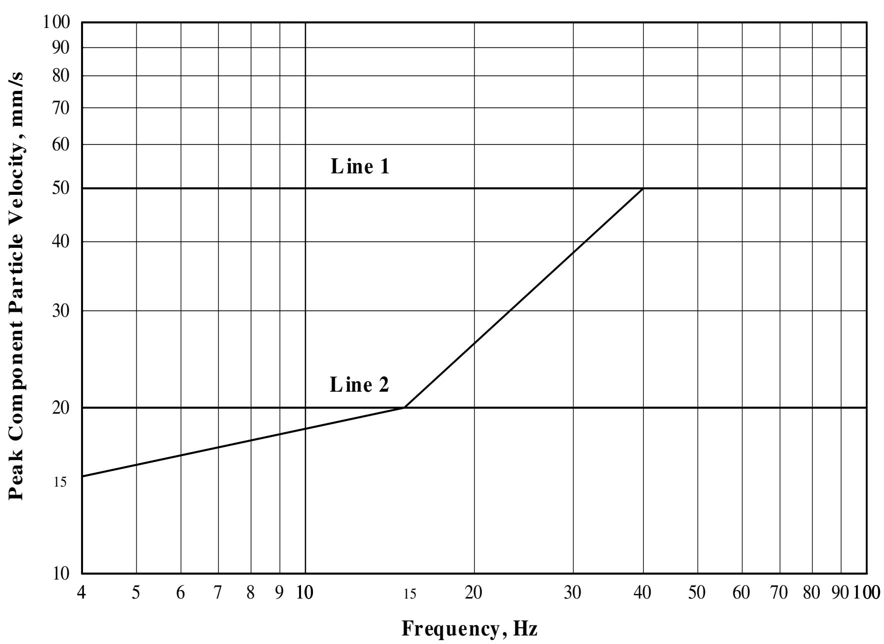

Figure 1: Summary of damage thresholds for transient vibration on domestic structures

The Standard indicates (refer to Figure 1), 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"* (Reference 14). 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 Table8 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 8: Vibration Limits Relating to Minor or Cosmetic Damage to Buildings from Piling Operations (from BS 5228: Part 4: 1992)

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.

Baseline Noise and Vibration Measurements

Locations for baseline noise monitoring were decided in conjunction with the Environmental Health Departments of Glasgow City and Renfrewshire councils.

A series of short term attended measurements were made at four positions along the route. The majority of the measurements were made in the vicinity of the proposed new branch line. Since the existing levels of railway noise in this area are relatively low compared to the rail corridor close to Glasgow City Centre.

The monitoring procedures adopted were in conformance with the requirements of BS 7445:1991 *'Description and measurement of environmental noise'* (Reference 15). The full results are presented in Table 9

Table 9 Noise Monitoring Results

Position A – Greenock Road (adjacent to St James' Park)							
Date	**Time**	$L_{Aeq,T}$	$L_{A90,T}$	$L_{A10,T}$	$L_{Amax,T}$	$L_{Amin,T}$	**Principal Noise Sources**
16/03/05	12:45-13:15	63.2	60.1	63.8	80.3	57.4	Noise from M8, A726 (Greenock Road), occasional aircraft taking off from airport (except night-time).
	19:30-20:00	61.7	58.7	62.3	84.4	55.9	
	23:35-23:50	55.1	52.1	57.1	65.1	48.6	
17/03/05	11:46-12:16	62.8	60.0	64.1	72.9	57.2	
Position B – Murray Street opposite residential housing, adjacent to railway line) ***Facade***							
Date	**Time**	$L_{Aeq,T}$	$L_{A90,T}$	$L_{A10,T}$	$L_{Amax,T}$	$L_{Amin,T}$	**Principal Noise Sources**
16/03/05	13:35-14:05	66.0	48.4	67.8	87.3	45.4	Mixed traffic on Murray Street, occasional aircraft taking off from airport (except night-time), occasional trains passing (except night-time).
	14:10-14:25	67.1	48.9	71.1	83.9	46.8	
	20:32-20:55	64.7	45.6	68.7	80.0	43.3	
17/03/05	00:19-00:35	52.7	41.8	52.2	79.5	38.8	
	11:09-11:41	66.7	47.5	69.6	87.1	45.0	
	14:45-15:00	67.1	55.2	70.7	82.5	53.9	
Position C – Clark Street adjacent to residential property, opposite Airlink airport parking							
Date	**Time**	$L_{Aeq,T}$	$L_{A90,T}$	$L_{A10,T}$	$L_{Amax,T}$	$L_{Amin,T}$	**Principal Noise Sources**
16/03/05	15:10-16:05	66.1	53.5	69.8	89.8	50.8	Mixed traffic on Clark Street and Greenhill Road, occasional aircraft taking off from airport (except night-time), occasional trains passing (except night-time).
	20:06-20:24	60.5	49.7	63.1	79.9	47.6	
17/03/05	00:00-00:15	43.2	41.9	44.4	49.1	40.6	
	10:32-11:00	64.4	52.2	67.5	84.6	48.1	
	14:21-14:40	61.7	55.3	66.3	72.0	54.5	
Position D – Rear of 46 Queen Elizabeth Ave, adjacent to Hillington West Station							
Date	**Time**	$L_{Aeq,T}$	$L_{A90,T}$	$L_{A10,T}$	$L_{Amax,T}$	$L_{Amin,T}$	**Principal Noise Sources**
16/03/05	16:44-17:14	58.7	48.3	54.3	76.9	46.4	Occasional trains passing (except night-time), distant road traffic noise on Queen Elizabeth Ave.

	17:17-17:46	57.9	47.9	56.0	80.3	46.3	
	21:12-21:40	54.1	45.0	54.9	76.0	45.7	
17/03/05	00:55-01:10	41.1	37.7	42.3	46.0	40.0	
	12:38-13:10	53.3	46.2	53.2	77.1	43.9	

The range of day, evening and night-time ambient noise levels monitored is not unusual for suburban and semi-suburban areas and generally lower that the nationwide average levels. The most recent National Noise Incidence survey found that 54% of the population of the UK live in dwellings exposed to daytime (07:00-23:00) noise levels above 55 dB L_{Aeq} and 67% to night-time noise levels above 45 dB L_{Aeq}.

In order to assess existing levels of vibration at representative receptors along the existing rail corridor a series of short term vibration measurements were conducted at the same locations as for the noise survey.

Vibration measurements were undertaken with a fully calibrated Vibroc V901-2 seismograph. The V901 is a tri-axial vibration analyser with electronic data storage of events. The unit is dual channel, enabling simultaneous analysis of two tri-axial transducers with continuous vibration monitoring to provide peak particle velocity (ppv) measurements on one channel and vibration dose values (VDV) assessment on the second channel. The vibration transducers were positioned on kerbstones, which have a large mass and are firmly embedded in the ground. After levelling the transducers, a 25 kg bag of sand was carefully positioned over them to ensure a firm and stable contact was made with the ground surface.

The results are presented in Table 10. The survey was conducted in accordance with the appropriate standards.

Table 10 Vibration Monitoring Results

Position A – Greenock Road adjacent to St James' Park									
Date	**Time**	**VDV – x $m/s^{1.75}$**		**VDV – y $m/s^{1.75}$**		**VDV – z $m/s^{1.75}$**		**PPV m/s**	**Significant Vibration Sources**
		1 hr	16 hr	1 hr	16 hr	1 hr	16 hr		
16/03/05	12:45-13:15	0.03411	0.06823	0.03347	0.06693	0.01794	0.03589	0.341	Occasional car passing on Greenock Road
	23:35-23:50	0.01655	-	0.01445	-	0.01317	-	0.141	
Position B – Murray Street opposite residential housing, adjacent to railway line									
Date	**Time**	**VDV – x $m/s^{1.75}$**		**VDV – y $m/s^{1.75}$**		**VDV – z $m/s^{1.75}$**		**PPV m/s**	**Significant Vibration Sources**
		1 hr	16 hr	1 hr	16 hr	1 hr	16 hr		
16/03/05	13:35-14:05	0.10983	0.21967	0.17076	0.34153	0.07923	0.15845	0.863	Mixed traffic on Murray St, occasional trains passing (except night-time).
	20:32-20:55	0.33318	0.66636	0.34159	0.68318	0.14533	0.29067	0.823	
17/03/05	00:19-00:35	0.01954	-	0.01586	-	0.01411	-	0.221	
	11:09-11:41	0.07082	0.14164	0.06935	0.13871	0.05996	0.11992	0.663	
	14:45-15:00	0.09233	0.18467	0.10044	0.20088	0.08416	0.16833	0.622	
Position C1 – Clark Street adjacent to residential property, opposite Airlink parking									

Date	Time	VDV – x $m/s^{1.75}$		VDV – y $m/s^{1.75}$		VDV – z $m/s^{1.75}$		PPV m/s	Significant Vibration Sources
		1 hr	16 hr	1 hr	16 hr	1 hr	16 hr		
17/03/05	00:00-00:15	0.01724	-	0.01035	-	0.01324	-	0.141	Mixed traffic on Clark St, occasional trains passing (except night-time).
	10:32-11:00	0.02283	0.04566	0.01826	0.03653	0.01735	0.03471	0.361	
	14:21-14:40	0.02298	0.04595	0.02039	0.04078	0.01973	0.03946	0.261	
Position C2 – Junction of Clark Street and Greenhill Road									
Date	**Time**	**VDV – x $m/s^{1.75}$**		**VDV – y $m/s^{1.75}$**		**VDV – z $m/s^{1.75}$**		**PPV m/s**	**Significant Vibration Sources**
		1 hr	16 hr	1 hr	16 hr	1 hr	16 hr		
16/03/05	15:10-16:05	0.06216	0.12431	0.08549	0.17098	0.10111	0.20222	0.863	Traffic on Clark St & Greenhill Rd, trains passing.
	20:06-20:24	0.05173	0.10345	0.04065	0.08130	0.04382	0.08764	0.462	
Position D – Rear of 46 Queen Elizabeth Ave, adjacent to Hillington West Station									
Date	**Time**	**VDV – x $m/s^{1.75}$**		**VDV – y $m/s^{1.75}$**		**VDV – z $m/s^{1.75}$**		**PPV m/s**	**Significant Vibration Sources**
		1 hr	16 hr	1 hr	16 hr	1 hr	16 hr		
16/03/05	16:44-17:14	0.07785	0.15570	0.03997	0.07995	0.01755	0.03510	0.321	Occasional trains passing (except night-time).
	21:12-21:40	0.03276	0.06553	0.05215	0.10431	0.02200	0.04400	0.301	
17/03/05	00:48-01:03	0.01655	-	0.01072	-	0.01324	-	0.141	
	12:38-13:10	0.07122	0.14244	0.03654	0.07308	0.01709	0.03418	0.313	

Railway Construction Noise and Vibration

Noise

Noise levels generated by a development and experienced by local receptors depends upon a number of variables, the most significant of which are:

4. the noise generated by plant or equipment used on site, rail traffic, road traffic and other sources, generally expressed as sound power levels (SWL);

5. the periods of operation of the plant on the site, known as its "on-time" (which may be 100% for fixed plant such as fans and boilers);

6. the distance between the noise source and the receptor;

7. the attenuation due to ground absorption, air absorption and barrier effects;

8. in some instances, the reflection of noise due to the presence of hard surfaces such as the sides of buildings or quarry faces.

The prediction method used in this assessment for construction and fixed plant noise sources is based on BS 5228: 1997, Part 1 which is used to predict noise as a free-field equivalent continuous noise level averaged over a one-hour period ($L_{Aeq,1h}$).

Construction plant, scheduling and phasing is not currently available for the proposed development. For each activity, free-field $L_{Aeq,1h}$ values were calculated at the nearest sensitive receptors. In most cases, it was assumed that a 2 metre temporary or permanent barrier was in place to shield sensitive receptors from work on the line, apart for the M8 bridge construction. Construction compounds located near sensitive receptors were assumed to be enclosed by 2 metre boarding.

The results are given in Tables 11a-11i Prediction calculations show that, in a number of locations predicted noise levels will exceed the short term limit of 70 dB $L_{Aeq,1h}$. The principal construction activity causing these exceedences is the viaduct construction and track installation, in particular the use of a rail saw.

Temporary site barriers of at least 2 metre high should be employed wherever practicable. Also, the use of temporary screens, close to the work, during welding and jointing and rail stressing would reduce noise levels to below the short-term limit and is recommended. Best construction practice to minimise the generation of noise should be employed at all times.

It should be noted that the plant noise source data in BS5228 is now in the order of 10 years old or more and it is likely that contemporary plant will be quieter. These levels should therefore be considered as a worst case.

Vibration

With the exception of certain types of piling construction plant, equipment likely to be used at the various construction areas are not recognised as sources of high levels of environmental vibration. Additionally, due to the nature of the work, construction activities will not be carried out for extended periods of time near sensitive receptors and vibration resulting from line work and operation of compounds is unlikely to be problematic.

Vibration from any necessary piling work on the elevated sections of the airport branch line would depend upon local ground conditions and the type of equipment used. British Standard BS 5228: part 4 lists ppvs measured at various distances from rotary bored piling operations and from these values and the calculation procedure listed in BS 6472 it is possible to empirically predict the daytime VDV at the nearest sensitive receptors, which will be the properties at the northern end of Greenock Road, approximately 70 metres distant.

A typical rotary bored piling rig would generate a ppv of the order of 0.54 mms^{-1} at 5m from the operation (from BS 5228: part 4, 1992). Using the propagation relationship given in BS 5228, this results in a ppv of 0.04 mms^{-1} at properties at Greenock Road, well below the level required to cause even cosmetic damage to properties and probably below the level of human perception. A steady piling vibration level of 0.04 mms^{-1} equates to an acceleration level, from BS 6472, of less than 0.005 ms^{-2}. When operating continually for a 10-hour day the corresponding vibration dose value, VDV, at properties in Greenock Road is calculated to be less than 0.10 $ms^{-1.75}$. This predicted daytime VDV is well below the bottom end of the range for 'low probability of adverse comment' (0.20-0.40 $ms^{-1.75}$), and complaints regarding vibration from piling work on the elevated section over the M8 are considered unlikely.

Table 7a: Construction of GARL Scheme Calculated $L_{Aeq,1\ h}$ values

				TYPICAL DEMOLITION AND CONSTRUCTION ROUTINES: AIRPORT STATION											
							Holiday Inn								
							Calculations to BS 5228								
Task	**Plant**	**SWL**	**Dist.**	**Dist.**	**Barrier**	**Grnd**	**Total**	**Result**	**trav'se**	**Min.**	**Dist.**	**Corrn**	**Act'vty**	**Corr**	**Noise**
	Type	**dB(A)**	**(m)**	**Attn.**	**Attn**	**Attn**	**Attn**	**SPL**	**dist.**	**dist.**	**Ratio**	**Factor**	**Dur.**	**Ontime**	**Level**
Excavation of Foundations	Excavator	110	23	35.2	10	0.0	45.2	64.8	10	54	0.2	1.0	0.83	0.83	63.96
	Lorries	105	23	35.2	10	0.0	45.2	59.8	50	54	0.9	0.7	0.83	0.58	57.41
	Piling Rig	107	23	35.2	10	0.0	45.2	61.8	0	54	0.0	1.0	0.83	0.83	60.96
Laying Foundations	Concrete Pump	118	23	35.2	10	0.0	45.2	72.8	0	54	0.0	1.0	0.83	0.83	71.96
	Concrete Mixer	110	23	35.2	10	0.0	45.2	64.8	0	54	0.0	1.0	0.83	0.83	63.96
	Lorries	105	23	35.2	10	0.0	45.2	59.8	50	54	0.9	0.7	0.83	0.58	57.41
	Poker vibrator	100	23	35.2	10	0.0	45.2	54.8	0	54	0.0	1.0	0.83	0.83	53.96
								0.0						**Total**	**73.7**
Viaduct/platform construction	Concrete Pump	118	23	35.2	0	-0.2	35.0	83.0	0	54	0.0	1.0	0.83	0.83	82.15
	Concrete Mixer	110	23	35.2	10	0.0	45.2	64.8	0	54	0.0	1.0	0.83	0.83	63.96
	batching plant	106	23	35.2	10	0.0	45.2	60.8	0	54	0.0	1.0	0.83	0.83	59.96
	Lorries	105	23	35.2	10	0.0	45.2	59.8	50	54	0.9	0.7	0.83	0.58	57.41
	Poker vibrator	100	23	35.2	0	-0.2	35.0	65.0	0	54	0.0	1.0	0.83	0.83	64.15
	Crane	109	23	35.2	0	-0.2	35.0	74.0	0	54	0.0	1.0	0.83	0.83	73.15
	chipping hammer	106	23	35.2	0	-0.2	35.0	71.0	0	54	0.0	1.0	0.83	0.83	70.15
														Total	**83.0**
Installation of new track	Excavator	110	23	35.2	0	-0.2	35.0	75.0	10	23	0.4	1.0	0.83	0.83	74.15
	Compactor	105	23	35.2	0	-0.2	35.0	70.0	0	23	0.0	1.0	0.83	0.83	69.15
	Crane	109	23	35.2	0	-0.2	35.0	74.0	0	23	0.0	1.0	0.83	0.83	73.15
	Excavator	110	23	35.2	0	-0.2	35.0	75.0	10	23	0.4	1.0	0.83	0.83	74.15
	Rail Saw	124	23	35.2	0	-0.2	35.0	89.0	0	23	0.0	1.0	0.15	0.15	80.72
	Grinder	111	23	35.2	0	-0.2	35.0	76.0	0	23	0.0	1.0	0.15	0.15	67.72
	Welding Kit	60	23	35.2	0	-0.2	35.0	25.0	0	23	0.0	1.0	0.15	0.15	16.72
	Tamper	113	23	35.2	0	-0.2	35.0	78.0	0	23	0.0	1.0	0.15	0.15	69.7
	Works Train	102	23	35.2	0	-0.2	35.0	67.0	25	23	1.1	0.8	0.50	0.40	62.98
	Rail Saw	124	23	35.2	0	-0.2	35.0	89.0	0	23	0.0	1.0	0.15	0.15	80.72
	Grinder	111	23	35.2	0	-0.2	35.0	76.0	0	23	0.0	1.0	0.15	0.15	67.72
	De-stressing kit	111	23	35.2	0	-0.2	35.0	76.0	0	23	0.0	1.0	0.15	0.15	67.72
														Total	**85.4**
Installation of signalling	Excavator	110	23	35.2	0	-0.2	35.0	75.0	10	23	0.4	1.0	0.83		
	Loading Crane	109	23	35.2	0	-0.2	35.0	74.0	0	23	0.0	1.0	0.83		
	Disc Cutter	112	23	35.2	0	-0.2	35.0	77.0	0	23	0.0	1.0	0.15	0.15	68.72
	Excavator	110	23	35.2	0	-0.2	35.0	75.0	10	23	0.4	1.0	0.83	0.83	74.15
	Works Train	102	23	35.2	0	-0.2	35.0	67.0	25	23	1.1	0.8	0.50	0.40	62.98
														Total	**75.5**

	TYPICAL DEMOLITION AND CONSTRUCTION ROUTINES: FUEL FARM CONSTRUCTION													
					176 Greenock Road									
					Calculations to BS 5228									
Plant	**SWL**	**Dist.**	**Dist.**	**Barrier**	**Grnd**	**Total**	**Result**	**trav'se**	**Min.**	**Dist.**	**Corrn**	**Act'vty**	**Corr**	**Noise**
Type	**dB(A)**	**(m)**	**Attn.**	**Attn**	**Attn**	**Attn**	**SPL**	**dist.**	**dist.**	**Ratio**	**Factor**	**Dur.**	**Ontime**	**Level**
								ltr	dmin	ltr/dmin	F	Tt	tc	$L_{Aeq,1h}$
Operation:	**Piling**													
piling rig	113	115	49.2	0	3.3	52.5	60.5	0	115	0.0	1	0.83	0.83	59.67
4 water pumps	103	115	49.2	0	3.3	52.5	50.5	0	115	0.0	1	1.00	1.00	50.48
1 concrete pump	103	115	49.2	0	3.3	52.5	50.5	0	115	0.0	1	1.00	1.00	50.48
concrete poker	100	115	49.2	0	3.3	52.5	47.5	0	115	0.0	1	0.83	0.83	46.67
compressor	98	115	49.2	0	3.3	52.5	45.5	0	115	0.0	1	1.00	1.00	45.48
generator	98	115	49.2	0	3.3	52.5	45.5	0	115	0.0	1	1.00	1.00	45.48
crane	105	115	49.2	0	3.3	52.5	52.5	25	115	0.2	1	0.83	0.83	51.67
													Total	**61.5**
Operation:	**Laying sub-base**													
bulldozer	108	115	49.2	0	3.3	52.5	55.5	25	115	0.2	1	0.50	0.50	52.47
dump truck	106	115	49.2	0	3.3	52.5	53.5	25	115	0.2	1	0.50	0.50	50.47
rammer	111	115	49.2	0	3.3	52.5	58.5	0	115	0.0	1	0.25	0.25	52.46
													Total	**56.7**
Operation:	**Surfacing**													
asphalt spreader	106	115	49.2	0	3.3	52.5	53.5	25	115	0.2	1	0.83	0.83	52.67
roller	103	115	49.2	0	3.3	52.5	50.5	25	115	0.2	1	0.83	0.83	49.67
													Total	**54.4**
Operation	**Tank construction**													
crane	105	115	49.2	0	3.3	52.5	52.5	25	115	0.2	1	0.83	0.83	51.67
Lorries	105	115	49.2	1	0.0	50.2	54.8	25	115	0.2	1	0.83	0.83	53.98
Nut runner	112	115	49.2	2	0.0	51.2	60.8	0	115	0.0	1	0.83	0.83	59.98
Percussion drill	104	115	49.2	3	0.0	52.2	51.8	0	115	0.0	1	0.83	0.83	50.98
Disc cutter	112	115	49.2	4	0.0	53.2	58.8	0	115	0.0	1	0.83	0.83	57.98
Grinder	112	115	49.2	5	0.0	54.2	57.8	0	115	0.0	1	0.83	0.83	56.98
Compressor	106	115	49.2	6	0.0	55.2	50.8	0	115	0.0	1	0.83	0.83	49.98
Generator	104	115	49.2	7	0.0	56.2	47.8	0	115	0.0	1	0.83	0.83	46.98
Welding Kit	60	115	49.2	8	0.0	57.2	2.8	0	115	0.0	1	0.83	0.83	1.98
													Total	**64.5**

		TYPICAL DEMOLITION AND CONSTRUCTION ROUTINES: BRANCHLINE & VIADUCT CONSTRUCTION													
							176 Greenock Road								
							Calculations to BS 5228								
	Plant	**SWL**	**Dist.**	**Dist.**	**Barrier**	**Grnd**	**Total**	**Result**	**trav'se**	**Min.**	**Dist.**	**Corrn**	**Act'vty**	**Corr**	**Noise**
	Type	**dB(A)**	**(m)**	**Attn.**	**Attn**	**Attn**	**Attn**	**SPL**	**dist.**	**dist.**	**Ratio**	**Factor**	**Dur.**	**Ontime**	**Level**
Excavation of Foundations	Excavator	110	54	42.6	10	0.0	52.6	57.4	10	54	0.2	1.0	0.83	0.83	56.54
	Lorries	105	54	42.6	10	0.0	52.6	52.4	50	54	0.9	0.7	0.83	0.58	49.99
Piling	Piling Rig	107	54	42.6	10	0.0	52.6	54.4	0	54	0.0	1.0	0.83	0.83	53.54
Laying Foundations	Concrete Pump	118	54	42.6	10	0.0	52.6	65.4	0	54	0.0	1.0	0.83	0.83	64.54
	Concrete Mixer	110	54	42.6	10	0.0	52.6	57.4	0	54	0.0	1.0	0.83	0.83	56.54
	Lorries	105	54	42.6	10	0.0	52.6	52.4	50	54	0.9	0.7	0.83	0.58	49.99
	Poker vibrator	100	54	42.6	10	0.0	52.6	47.4	0	54	0.0	1.0	0.83	0.83	46.54
								0.0						**Total**	**66.3**
Viaduct construction	Concrete Pump	118	54	42.6	0	1.7	44.3	73.7	0	54	0.0	1.0	0.83	0.83	72.88
	Concrete Mixer	110	54	42.6	10	0.0	52.6	57.4	0	54	0.0	1.0	0.83	0.83	56.54
	batching plant	106	54	42.6	10	0.0	52.6	53.4	0	54	0.0	1.0	0.83	0.83	52.54
	Lorries	105	54	42.6	10	0.0	52.6	52.4	50	54	0.9	0.7	0.83	0.58	49.99
	Poker vibrator	100	54	42.6	0	1.7	44.3	55.7	0	54	0.0	1.0	0.83	0.83	54.88
	Crane	109	54	42.6	0	1.7	44.3	64.7	0	54	0.0	1.0	0.83	0.83	63.88
	chipping hammer	106	54	42.6	0	1.7	44.3	61.7	0	54	0.0	1.0	0.83	0.83	60.88
														Total	**73.8**
Installation of new track	Excavator	110	54	42.6	0	1.7	44.3	65.7	10	54	0.2	1.0	0.83	0.83	64.88
	Compactor	105	54	42.6	0	1.7	44.3	60.7	0	54	0.0	1.0	0.83	0.83	59.88
	Crane	109	54	42.6	0	1.7	44.3	64.7	0	54	0.0	1.0	0.83	0.83	63.88
	Excavator	110	54	42.6	0	1.7	44.3	65.7	10	54	0.2	1.0	0.83	0.83	64.88
	Rail Saw	124	54	42.6	0	1.7	44.3	79.7	0	54	0.0	1.0	0.15	0.15	71.45
	Grinder	111	54	42.6	0	1.7	44.3	66.7	0	54	0.0	1.0	0.15	0.15	58.45
	Welding Kit	60	54	42.6	0	1.7	44.3	15.7	0	54	0.0	1.0	0.15	0.15	7.45
	Tamper	113	54	42.6	0	1.7	44.3	68.7	0	54	0.0	1.0	0.15	0.15	60.5
	Works Train	102	54	42.6	0	1.7	44.3	57.7	25	54	0.5	0.8	0.50	0.40	53.71
	Rail Saw	124	54	42.6	0	1.7	44.3	79.7	0	54	0.0	1.0	0.15	0.15	71.45
	Grinder	111	54	42.6	0	1.7	44.3	66.7	0	54	0.0	1.0	0.15	0.15	58.45
	De-stressing kit	111	54	42.6	0	1.7	44.3	66.7	0	54	0.0	1.0	0.15	0.15	58.45
														Total	**76.1**
Installation of signalling	Excavator	110	54	42.6	0	1.7	44.3	65.7	10	54	0.2	1.0	0.83		
	Loading Crane	109	54	42.6	0	1.7	44.3	64.7	0	54	0.0	1.0	0.83		
	Disc Cutter	112	54	42.6	0	1.7	44.3	67.7	0	54	0.0	1.0	0.15	0.15	59.45
	Excavator	110	54	42.6	0	1.7	44.3	65.7	10	54	0.2	1.0	0.83	0.83	64.88
	Works Train	102	54	42.6	0	1.7	44.3	57.7	25	54	0.5	0.8	0.50	0.40	53.71
														Total	**66.2**

			TYPICAL DEMOLITION AND CONSTRUCTION ROUTINES: WALLNEUK JUNCTION												
							3 Incle Street								
							Calculations to BS 5228								
	Plant	**SWL**	**Dist.**	**Dist.**	**Barrier**	**Grnd**	**Total**	**Result**	**trav'se**	**Min.**	**Dist.**	**Corrn**	**Act'vty**	**Corr**	**Noise**
	Type	**dB(A)**	**(m)**	**Attn.**	**Attn**	**Attn**	**Attn**	**SPL**	**dist.**	**dist.**	**Ratio**	**Factor**	**Dur.**	**Ontime**	**Level**
									ltr	dmin	ltr/dmin	F	Tt	tc	$L_{Aeq,1h}$
												(manual)			
	Chain saw	110	5	22.0	10	0.0	32.0	78.0	0	5	0.0	1.0	0.30	0.30	72.79
Clearance of slopes	Dumper Trucks	112	5	22.0	10	0.0	32.0	80.0	50	5	10.0	0.5	0.83	0.43	76.37
														Total	**78.0**
Installation of new track	Excavator	110	5	22.0	10	0.0	32.0	78.0	10	5	2.0	1.0	0.83	0.83	77.21
	Compactor	105	5	22.0	10	0.0	32.0	73.0	0	5	0.0	1.0	0.83	0.83	72.21
	Crane	109	5	22.0	10	0.0	32.0	77.0	0	5	0.0	1.0	0.83	0.83	76.21
	Excavator	110	5	22.0	10	0.0	32.0	78.0	10	5	2.0	1.0	0.83	0.83	77.21
	Rail Saw	124	5	22.0	10	0.0	32.0	92.0	0	5	0.0	1.0	0.15	0.15	83.78
	Grinder	111	5	22.0	10	0.0	32.0	79.0	0	5	0.0	1.0	0.15	0.15	70.78
	Welding Kit	60	5	22.0	10	0.0	32.0	28.0	0	5	0.0	1.0	0.15	0.15	19.78
	Tamper	113	5	22.0	10	0.0	32.0	81.0	0	5	0.0	1.0	0.15	0.15	72.8
	Works Train	102	5	22.0	10	0.0	32.0	70.0	25	5	5.0	0.8	0.50	0.40	66.04
	Rail Saw	124	5	22.0	10	0.0	32.0	92.0	0	5	0.0	1.0	0.15	0.15	83.78
	Grinder	111	5	22.0	10	0.0	32.0	79.0	0	5	0.0	1.0	0.15	0.15	70.78
	De-stressing kit	111	5	22.0	10	0.0	32.0	79.0	0	5	0.0	1.0	0.15	0.15	70.78
														Total	**88.5**
Installation of signalling	Excavator	110	5	22.0	10	0.0	32.0	78.0	10	5	2.0	1.0	0.83		
	Loading Crane	109	5	22.0	10	0.0	32.0	77.0	0	5	0.0	1.0	0.83		
	Disc Cutter	112	5	22.0	10	0.0	32.0	80.0	0	5	0.0	1.0	0.15	0.15	71.78
	Excavator	110	5	22.0	10	0.0	32.0	78.0	10	5	2.0	1.0	0.83	0.83	77.21
	Works Train	102	5	22.0	10	0.0	32.0	70.0	25	5	5.0	0.8	0.50	0.40	66.04
														Total	**78.6**

TYPICAL DEMOLITION AND CONSTRUCTION ROUTINES: ARKLESTON JUNCTION

16 Arkleston Crescent

Calculations to BS 5228

	Plant Type	**SWL dB(A)**	**Dist. (m)**	**Dist. Attn.**	**Barrier Attn**	**Grnd Attn**	**Total Attn**	**Result SPL**	**trav'se dist.** ltr	**Min. dist.** dmin	**Dist. Ratio** ltr/dmin	**Corrn Factor** F (manual)	**Act'vty Dur.** Tt	**Corr Ontime** tc	**Noise Level** $L_{Aeq,1h}$
	Chain saw	110	43	40.7	10	0.0	50.7	59.3	0	43	0.0	1.0	0.30	0.30	54.10
Clearance of slopes	Dumper Trucks	112	43	40.7	10	0.0	50.7	61.3	50	43	1.2	0.5	0.83	0.43	57.68
														Total	**59.3**
Installation of new track	Excavator	110	43	40.7	10	0.0	50.7	59.3	10	43	0.2	1.0	0.83	0.83	58.52
	Compactor	105	43	40.7	10	0.0	50.7	54.3	0	43	0.0	1.0	0.83	0.83	53.52
	Crane	109	43	40.7	10	0.0	50.7	58.3	0	43	0.0	1.0	0.83	0.83	57.52
	Excavator	110	43	40.7	10	0.0	50.7	59.3	10	43	0.2	1.0	0.83	0.83	58.52
	Rail Saw	124	43	40.7	10	0.0	50.7	73.3	0	43	0.0	1.0	0.15	0.15	65.09
	Grinder	111	43	40.7	10	0.0	50.7	60.3	0	43	0.0	1.0	0.15	0.15	52.09
	Welding Kit	60	43	40.7	10	0.0	50.7	9.3	0	43	0.0	1.0	0.15	0.15	1.09
	Tamper	113	43	40.7	10	0.0	50.7	62.3	0	43	0.0	1.0	0.15	0.15	54.1
	Works Train	102	43	40.7	10	0.0	50.7	51.3	25	43	0.6	0.8	0.50	0.40	47.35
	Rail Saw	124	43	40.7	10	0.0	50.7	73.3	0	43	0.0	1.0	0.15	0.15	65.09
	Grinder	111	43	40.7	10	0.0	50.7	60.3	0	43	0.0	1.0	0.15	0.15	52.09
	De-stressing kit	111	43	40.7	10	0.0	50.7	60.3	0	43	0.0	1.0	0.15	0.15	52.09
														Total	**69.8**
Installation of signalling	Excavator	110	43	40.7	10	0.0	50.7	59.3	10	43	0.2	1.0	0.83	0.83	58.52
	Loading Crane	109	43	40.7	10	0.0	50.7	58.3	0	43	0.0	1.0	0.83	0.83	57.52
	Disc Cutter	112	43	40.7	10	0.0	50.7	61.3	0	43	0.0	1.0	0.15	0.15	53.09
	Excavator	110	43	40.7	10	0.0	50.7	59.3	10	43	0.2	1.0	0.83	0.83	58.52
	Works Train	102	43	40.7	10	0.0	50.7	51.3	25	43	0.6	0.8	0.50	0.40	47.35
														Total	**63.5**

			TYPICAL DEMOLITION AND CONSTRUCTION ROUTINES: THIRD BI_DIRECTIONAL MAINLINE TRACK												
						184 Linburn Road									
						Calculations to BS 5228									
	Plant	**SWL**	**Dist.**	**Dist.**	**Barrier**	**Grnd**	**Total**	**Result**	**trav'se**	**Min.**	**Dist.**	**Corrn**	**Act'vty**	**Corr**	**Noise**
	Type	**dB(A)**	**(m)**	**Attn.**	**Attn**	**Attn**	**Attn**	**SPL**	**dist.**	**dist.**	**Ratio**	**Factor**	**Dur.**	**Ontime**	**Level**
									ltr	dmin	ltr/dmin	F	Tt	tc	$L_{Aeq,1h}$
												(manual)			
	Chain saw	110	36	39.1	10	0.0	49.1	60.9	0	36	0.0	1.0	0.30	0.30	55.65
Clearance of slopes	Dumper Trucks	112	36	39.1	10	0.0	49.1	62.9	50	36	1.4	0.5	0.83	0.43	59.22
														Total	**60.8**
Installation of new track	Excavator	110	36	39.1	10	0.0	49.1	60.9	10	36	0.3	1.0	0.83	0.83	60.06
	Compactor	105	36	39.1	10	0.0	49.1	55.9	0	36	0.0	1.0	0.83	0.83	55.06
	Crane	109	36	39.1	10	0.0	49.1	59.9	0	36	0.0	1.0	0.83	0.83	59.06
	Excavator	110	36	39.1	10	0.0	49.1	60.9	10	36	0.3	1.0	0.83	0.83	60.06
	Rail Saw	124	36	39.1	10	0.0	49.1	74.9	0	36	0.0	1.0	0.15	0.15	66.63
	Grinder	111	36	39.1	10	0.0	49.1	61.9	0	36	0.0	1.0	0.15	0.15	53.63
	Welding Kit	60	36	39.1	10	0.0	49.1	10.9	0	36	0.0	1.0	0.15	0.15	2.63
	Tamper	113	36	39.1	10	0.0	49.1	63.9	0	36	0.0	1.0	0.15	0.15	55.6
	Works Train	102	36	39.1	10	0.0	49.1	52.9	25	36	0.7	0.8	0.50	0.40	48.89
	Rail Saw	124	36	39.1	10	0.0	49.1	74.9	0	36	0.0	1.0	0.15	0.15	66.63
	Grinder	111	36	39.1	10	0.0	49.1	61.9	0	36	0.0	1.0	0.15	0.15	53.63
	De-stressing kit	111	36	39.1	10	0.0	49.1	61.9	0	36	0.0	1.0	0.15	0.15	53.63
														Total	**71.3**
Installation of signalling	Excavator	110	36	39.1	10	0.0	49.1	60.9	10	36	0.3	1.0	0.83		
	Loading Crane	109	36	39.1	10	0.0	49.1	59.9	0	36	0.0	1.0	0.83		
	Disc Cutter	112	36	39.1	10	0.0	49.1	62.9	0	36	0.0	1.0	0.15	0.15	54.63
	Excavator	110	36	39.1	10	0.0	49.1	60.9	10	36	0.3	1.0	0.83	0.83	60.06
	Works Train	102	36	39.1	10	0.0	49.1	52.9	25	36	0.7	0.8	0.50	0.40	48.89
														Total	**61.4**

			TYPICAL DEMOLITION AND CONSTRUCTION ROUTINES: GLASGOW CENTRAL STATION												
						32 Oswald Street									
						Calculations to BS 5228									
	Plant	**SWL**	**Dist.**	**Dist.**	**Barrier**	**Grnd**	**Total**	**Result**	**trav'se**	**Min.**	**Dist.**	**Corrn**	**Act'vty**	**Corr**	**Noise**
	Type	**dB(A)**	**(m)**	**Attn.**	**Attn**	**Attn**	**Attn**	**SPL**	**dist.**	**dist.**	**Ratio**	**Factor**	**Dur.**	**Ontime**	**Level**
									ltr	dmin	ltr/dmin	F	Tt	tc	$L_{Aeq,1h}$
												(manual)			
platform construction	Concrete Pump	118	31	37.8	0	0.5	38.3	79.7	0	54	0.0	1.0	0.83	0.83	78.91
	Concrete Mixer	110	31	37.8	10	0.0	47.8	62.2	0	54	0.0	1.0	0.83	0.83	61.36
	Lorries	105	31	37.8	10	0.0	47.8	57.2	50	54	0.9	0.7	0.83	0.58	54.81
	Poker vibrator	100	31	37.8	0	0.5	38.3	61.7	0	54	0.0	1.0	0.83	0.83	60.91
	Crane	109	31	37.8	0	0.5	38.3	70.7	0	54	0.0	1.0	0.83	0.83	69.91
	chipping hammer	106	31	37.8	0	0.5	38.3	67.7	0	54	0.0	1.0	0.83	0.83	66.91
														Total	**79.8**
Installation of new track	Excavator	110	31	37.8	0	0.5	38.3	71.7	10	31	0.3	1.0	0.83	0.83	70.91
	Compactor	105	31	37.8	0	0.5	38.3	66.7	0	31	0.0	1.0	0.83	0.83	65.91
	Crane	109	31	37.8	0	0.5	38.3	70.7	0	31	0.0	1.0	0.83	0.83	69.91
	Excavator	110	31	37.8	0	0.5	38.3	71.7	10	31	0.3	1.0	0.83	0.83	70.91
	Rail Saw	124	31	37.8	0	0.5	38.3	85.7	0	31	0.0	1.0	0.15	0.15	77.48
	Grinder	111	31	37.8	0	0.5	38.3	72.7	0	31	0.0	1.0	0.15	0.15	64.48
	Welding Kit	60	31	37.8	0	0.5	38.3	21.7	0	31	0.0	1.0	0.15	0.15	13.48
	Tamper	113	31	37.8	0	0.5	38.3	74.7	0	31	0.0	1.0	0.15	0.15	66.5
	Works Train	102	31	37.8	0	0.5	38.3	63.7	25	31	0.8	0.8	0.50	0.40	59.74
	Rail Saw	124	31	37.8	0	0.5	38.3	85.7	0	31	0.0	1.0	0.15	0.15	77.48
	Grinder	111	31	37.8	0	0.5	38.3	72.7	0	31	0.0	1.0	0.15	0.15	64.48
	De-stressing kit	111	31	37.8	0	0.5	38.3	72.7	0	31	0.0	1.0	0.15	0.15	64.48
														Total	**82.1**
Installation of signalling	Excavator	110	31	37.8	0	0.5	38.3	71.7	10	31	0.3	1.0	0.83		
	Loading Crane	109	31	37.8	0	0.5	38.3	70.7	0	31	0.0	1.0	0.83		
	Disc Cutter	112	31	37.8	0	0.5	38.3	73.7	0	31	0.0	1.0	0.15	0.15	65.48
	Excavator	110	31	37.8	0	0.5	38.3	71.7	10	31	0.3	1.0	0.83	0.83	70.91
	Works Train	102	31	37.8	0	0.5	38.3	63.7	25	31	0.8	0.8	0.50	0.40	59.74
														Total	**72.3**

TYPICAL DEMOLITION AND CONSTRUCTION ROUTINES: ELDERSLIE LOOP

Main Road, Elderslie

Calculations to BS 5228

	Plant Type	**SWL dB(A)**	**Dist. (m)**	**Dist. Attn.**	**Barrier Attn**	**Grnd Attn**	**Total Attn**	**Result SPL**	**trav'se dist.**	**Min. dist.**	**Dist. Ratio**	**Corrn Factor**	**Act'vty Dur.**	**Corr Ontime**	**Noise Level**
Installation of new track	Excavator	110	35	38.9	10	0.0	48.9	61.1	10	35	0.3	1.0	0.83	0.83	60.31
	Compactor	105	35	38.9	10	0.0	48.9	56.1	0	35	0.0	1.0	0.83	0.83	55.31
	Crane	109	35	38.9	10	0.0	48.9	60.1	0	35	0.0	1.0	0.83	0.83	59.31
	Excavator	110	35	38.9	10	0.0	48.9	61.1	10	35	0.3	1.0	0.83	0.83	60.31
	Rail Saw	124	35	38.9	10	0.0	48.9	75.1	0	35	0.0	1.0	0.15	0.15	66.88
	Grinder	111	35	38.9	10	0.0	48.9	62.1	0	35	0.0	1.0	0.15	0.15	53.88
	Welding Kit	60	35	38.9	10	0.0	48.9	11.1	0	35	0.0	1.0	0.15	0.15	2.88
	Tamper	113	35	38.9	10	0.0	48.9	64.1	0	35	0.0	1.0	0.15	0.15	55.9
	Works Train	102	35	38.9	10	0.0	48.9	53.1	25	35	0.7	0.8	0.50	0.40	49.14
	Rail Saw	124	35	38.9	10	0.0	48.9	75.1	0	35	0.0	1.0	0.15	0.15	66.88
	Grinder	111	35	38.9	10	0.0	48.9	62.1	0	35	0.0	1.0	0.15	0.15	53.88
	De-stressing kit	111	35	38.9	10	0.0	48.9	62.1	0	35	0.0	1.0	0.15	0.15	53.88
														Total	**71.6**
Installation of signalling	Excavator	110	35	38.9	10	0.0	48.9	61.1	10	35	0.3	1.0	0.83		
	Loading Crane	109	35	38.9	10	0.0	48.9	60.1	0	35	0.0	1.0	0.83		
	Disc Cutter	112	35	38.9	10	0.0	48.9	63.1	0	35	0.0	1.0	0.15	0.15	54.88
	Excavator	110	35	38.9	10	0.0	48.9	61.1	10	35	0.3	1.0	0.83	0.83	60.31
	Works Train	102	35	38.9	10	0.0	48.9	53.1	25	35	0.7	0.8	0.50	0.40	49.14
														Total	**61.7**

		TYPICAL DEMOLITION AND CONSTRUCTION ROUTINES: WALLNEUK CONSTRUCTION COMPOUND												
					223 GallowHill Road									
					Calculations to BS 5228									
Plant	**SWL**	**Dist.**	**Dist.**	**Barrier**	**Grnd**	**Total**	**Result**	**trav'se**	**Min.**	**Dist.**	**Corrn**	**Act'vty**	**Corr**	**Noise**
Type	**dB(A)**	**(m)**	**Attn.**	**Attn**	**Attn**	**Attn**	**SPL**	**dist.**	**dist.**	**Ratio**	**Factor**	**Dur.**	**Ontime**	**Level**
								ltr	dmin	ltr/dmin	F	Tt	tc	$L_{Aeq,1h}$
Forklift	98	12	29.6	10	0.0	39.6	58.4	10	12	0.8	1.0	0.83	0.83	57.61
Lorries	105	12	29.6	10	0.0	39.6	65.4	0	12	0.0	1.0	0.10	0.10	55.42
Generator	95	12	29.6	10	0.0	39.6	55.4	0	12	0.0	1.0	0.10	0.10	45.42
Handtools	105	12	29.6	10	0.0	39.6	65.4	0	12	0.0	1.0	0.10	0.10	55.42
													Total	**61.2**

Railway Operational Noise

For the supplied train schedule and speed profile, façade noise levels were calculated to either ground floor or first floor levels, depending on the building, using the Calculation of Railway Noise 1995 (CRN) (Reference 16) method, for selected properties fronting the railway corridor along the full length of the route. This method allows calculation of day (06:00-24:00) and night-time (24:00-06:00) railway noise levels. No noise mitigation was assumed.

Table 12 details the number of daytime/night-time (06:00-00:00/00:00-06:00) movements in both directions used for the noise assessment based on timetabling information supplied by the Transportation Division of Faber Maunsell.

Table 12 Train Flow data

Stretch	EMU[1]		DMU[2]		Freight	
	Do Min Day/night	Do Some Day/night	Do Min Day/night	Do Some Day/night	Do Min Day/night	Do Some Day/night
Glasgow Central-Shields Junc	331/8	455/20	86/7	79/0	0/0	0/0
Shields Junc-Cardonald Junction	290/0	426/5	5/0	5/0	71/1	66/4
Cardonald Junction - Paisley Gilmour St	283/0	425/3	5/0	5/0	64/1	58/1
Paisley Gilmour St-Paisley St James	136/0	280/3	0/0	0/0	0/0	0/0
Airport Branch	0/0	142/3	0/0	0/0	0/0	0/0

[1] Electric multiple unit
[2] Diesel multiple unit

It can be seen that the proposed scheme will substantially increase the number of passenger train movements passing through the existing rail corridor.

A wide range of different train types and class currently run on the route between Paisley St James and Glasgow Central stations, as set out in Table 9.

Table 13 Train Type Data

Train Type	EMU[1]	DMU[2]	Freight
Class	150,318,320,334	150,156,158,170	60,56,47, hauling freight of various types and weight

[1] Electric multiple unit
[2] Diesel multiple unit

The following simplifications/assumptions have been made in the CRN calculations:

1. The gradient is zero along the length of the route.
2. GARL service only is to use the 3rd bidirectional mainline.
3. The contribution from the 10 different types of freight traffic operating on the line have been simplified to one type.
4. In the absence of specific CRN noise data for the train types operating on the route, all EMUs are assumed to be Class 319 and DMUs Class 166.
5. All passenger services are composed of 8 carriages.
6. Due to a lack of data, for the mainline noise calculations, the topography between the railway line and the reception point has been assumed to be flat.
7. Train speeds have been based on the maximum operating speeds along the line

These results were used to assess the need for mitigation in the form of lineside barriers. Applying the defined methodology, all residential properties subject to a façade noise level (due to railway noise) equal to or greater than 55 dB $L_{Aeq,18h}$, and subject to an increase in free-field noise level equal to or greater than 5dB were considered for mitigation.

The CRN predicted noise levels are presented in Tables 7 and 8 of Chapter 13 in the main report..

Operational Mitigation

There is no recognised method for assessing the short-term impact of an increase in railway noise (although short-term impact assessment is reported in DMRB for increases in road traffic noise) due primarily to the lack of social studies along railways subject to abrupt increases (or reductions) in rail traffic. It is expected that in the short-term (from day of opening) there would be more residents annoyed by noise, this decreasing in the long term due to familiarisation. By considering a requirement for noise mitigation for areas subject to increases above 5 dB(A) (and above 55 dB(A)) it is considered that short-term annoyance has been reduced as far as reasonably practicable. Reference to the above table indicates that there would be only 48 properties subject to increases of 5-10 dB(A) (to above 55 dB $L_{Aeq,18h}$) and if every resident at each of those properties were 'annoyed' in the short term then this is equivalent to approximately 115 residents, this reducing in the long term to the final figure (concluded above) of less than 39 residents 'annoyed'. (Other residents along the route may be annoyed in the short-term but since the final railway noise level at their properties would be below 55 dB $L_{Aeq,18h}$ the implication is that in the long term those residents would not eventually be 'annoyed' by railway noise).

Specific to night-time sleep disturbance, the $L_{Amax,fast}$ level can be estimated from the train sound exposure level (SEL) using the equation;

$L_{Amax,fast} = 0.973\ SEL - 3.9 \log_{10}(t)$

Where t is the time taken for the train to pass (in seconds)

For a two car DMU travelling at 70 mph estimated façade noise levels are;-

$L_{Amax,fast}$ = 75 to 81 at 10 metres from the line, depending on the barrier attenuation

$L_{Amax,fast}$ = 70 to 72 at 20 metres from the line, depending on the barrier attenuation

Railway Operational Vibration

The equation used to correct the VDV to account for the number of pass-bys is:

$$VDV_{Total} = VDV_{Train} * N^{1/4}$$

Where N = number of trains

References

1) Guidelines for Community Noise, World Health Organisation, 1999

2) British Standard BS 8233: 1999 ‘Sound insulation and noise reduction for buildings – Code of practice’ British Standards Institution, 1999

3) British Standard BS 5228: 1997 ‘Noise and vibration control on construction and open sites’. British Standards Institution, 1997

4) Minerals Planning Guidance 11: The control of noise at surface mineral workings. Department of the Environment, The Welsh Office, April 1993

5) British Standard BS 4142: 1997 ‘Rating industrial noise affecting mixed residential and industrial areas’. British Standards Institution, 1997

6) Guidance on the Methodology for Multi-Modal (GoMMMS) Studies, DETR, 2000

7) Scottish Transport Appraisal (STAG) Guidance Chapter 6, Scottish, Executive 2003

8) Guidelines On Noise Impact Assessment (Draft), Joint Working Party of Institute of Acoustics and Institute of Environmental Management and Assessment, 2002

9) Noise Insulation Regulations (Railways and Other Guided Transport Systems), 1996.

10) Design Manual for Roads and Bridges Volume 11 Part 7, 1994. The Department of Transport

11) Planning Advice Note: PAN56. The Scottish Office, 1999

12) British Standard BS 6472: 1992 *Guide to Evaluation of human exposure to vibration in buildings (1 Hz to 80 Hz).* British Standards Institution 1992

13) British Standard BS 7385: Part 2: 1990 *Evaluation and measurement for vibration in buildings. Part 2. Guide for measurement of vibrations and evaluation of their effects on buildings.* British Standards Institute 1990

14) British Standard BS 5228: Part 4: 1992 *Noise control on construction and open sites. Part 4. Code of practice for noise and vibration control applicable to piling operations.* British Standards Institute 1992

15) British Standard BS 7445: 1991 ‘Description and Measurement of Environmental Noise’ British Standards Institution, 1991

16) Calculation of Railway Noise, Department of Transport, 1995