Sound, Noise and Vibration

An explanation

Rupert Thornely-Taylor
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Outline of Presentation

• What sound is - sources, and ways in which it is transmitted from source to receiver
• What vibration is - sources, and ways in which it is transmitted from source to receiver
• Human perception of sound and vibration
• Measurement scales and indices
• Assessment approaches - relationship between noise and vibration and human response to them
• Ways in which noise and vibration and their effects can be reduced
• Government policy regarding assessment and decision making
• HS2's application of government policy
Scope of sound and vibration issues

SURFACE CONSTRUCTION
TUNNEL CONSTRUCTION
SURFACE OPERATION - RAILWAY
SURFACE OPERATION - FIXED PLANT
UNDERGROUND OPERATION
Basics – what sound is

Sound is air oscillation that is propagated by wave motion

at frequencies between 20 cycles per second (called Hertz, abbreviated Hz) and 20,000 cycles per second (20kHz)
Basics – what sound is

Sound decays with distance –
It spreads out, is reduced by soft ground surfaces and by intervening obstacles

Sound decay is known as attenuation
Basics – what sound is

Sound is measured in decibels, abbreviated as dB
frequency-weighted to approximate the response of the human ear—in units of dB(A)
Basics – what sound is

Noise is unwanted sound

The human ear is much more complex than any sound level meter

Human beings are more complex still – there is no simple relationship between noise measurements and human response to the noise
Vibration is oscillation of solids that can be propagated through wave motion.

Vibration in soil decays with distance when it spreads out, and is also attenuated by energy absorption in the soil and by obstacles and discontinuities.
Vibration is mainly of interest in the frequency range 0.5Hz to 250Hz and is measured in units of acceleration, velocity or displacement, but it can give rise to audible sound which is then measured in decibels.
Basics – what vibration is

Like sound, vibration needs to be frequency-weighted to match the response of the human tactile senses.
Basics – what vibration is

As with sound, human response to vibration is much more complex than can be measured with a meter.
Basics - sound

Every 10 dB *increase* is about *double* the loudness

Every 10 dB *decrease* is about a *halving* of loudness
A 1 dB change is only perceptible under controlled conditions
Basics - sound

A 3 dB change is the minimum perceptible under normal conditions
## Basics - sound

<table>
<thead>
<tr>
<th>INDOOR</th>
<th>Noise Level, dB(A)</th>
<th>OUTDOOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rock Band</td>
<td>110</td>
<td>Underneath aircraft landing at 1km from runway</td>
</tr>
<tr>
<td>Night club</td>
<td>100</td>
<td>1m from pneumatic road breaker</td>
</tr>
<tr>
<td>Food blender at 1m</td>
<td>90</td>
<td>1m from petrol lawnmower</td>
</tr>
<tr>
<td>Vacuum cleaner at 1m</td>
<td>80</td>
<td>Pavement of city street</td>
</tr>
<tr>
<td>Loud voice at 1m</td>
<td>70</td>
<td>Aircraft at height of 200m</td>
</tr>
<tr>
<td>Normal voice at 1m</td>
<td>60</td>
<td>30m from petrol lawnmower</td>
</tr>
<tr>
<td>Open plan office</td>
<td>50</td>
<td>Lorry at 100m, heavy rainfall</td>
</tr>
<tr>
<td>Refrigerator at 1m</td>
<td>40</td>
<td>Suburban area at night, no local traffic</td>
</tr>
<tr>
<td>Concert hall background noise</td>
<td>30</td>
<td>Country area at night, no local traffic</td>
</tr>
<tr>
<td>Extremely quiet room</td>
<td>20</td>
<td>Very remote rural area no wind</td>
</tr>
<tr>
<td>Nearly Silent</td>
<td>10</td>
<td>Wilderness at night with no wind</td>
</tr>
<tr>
<td>Threshold of audibility</td>
<td>0</td>
<td>Threshold of audibility</td>
</tr>
</tbody>
</table>
Basics - sound

Sounds in the environment normally vary in level, for example due to the passage of vehicles, or trains. The sound level therefore varies with time, showing highs and lows. The highs are measured with an index called $L_{A\text{max}}$

$L_{A\text{max}}$ levels are presented in the tables in Volume 5 of the Environmental Statement. These are $L_{A\text{Fmax}}$ levels where F is the “fast” time weighting (0.125 second)
Basics - sound

Because many noise events are more annoying than a few noise events, an index is needed to take account of both level and number (and duration) of events.

Sounds that vary in level are therefore measured in equivalent continuous sound level, used internationally:

$$L_{eq,T} \text{ (or } L_{Aeq,T})$$

T = time period

$L_{Aeq,T}$ levels are presented both in the tables in Volume 5 of the Environmental Statement and also plotted as contours.
Basics - sound

$L_{Aeq}$ is not an average of sound levels
It is an index that is an average of the energy content of sound levels.

A sound which is twice as loud as another contains ten times the amount of energy.

So averaging the energy gives a result dominated by the highest sounds in the averaging process.

e.g. five events of equal duration measuring 50 dB together with one of 70 dB gives an ordinary arithmetic average of 53 dB — but the $L_{Aeq}$ value is 62 dB
$L_{Aeq}$ is no ordinary average…

Decibel scale

- Decibels: 30, 40, 50, 60, 70
- Time, seconds: 0, 50, 100, 150, 200, 250, 300, 350, 400

$L_{ASmax}$
$L_{Aeq}$ is no ordinary average...

Logarithmic energy scale

- Energy scale: $1000, 10000, 100000, 1000000, 10000000$
- Time scale: $0, 50, 100, 150, 200, 250, 300, 350, 400$

Logarithmic energy graph
$L_{Aeq}$ is no ordinary average...
$L_{Aeq}$ is no ordinary average...
Basics - sound

With $L_{Aeq}$:

doubling the energy in the sound,
doubling the number of sources,
doubling the duration of a sound event,
doubling the number of similar events
each give $+3\text{dB}$
Basics - sound

With $L_{Aeq}$:

ten times the energy in the sound,
ten times the number of sources,
ten times the duration of a sound event,
ten times the number of similar events

each give $+10\text{dB}$
Basics – sound and vibration

In terms of human response at environmental sound levels:

• Sound levels on their own mean nothing.
• Social surveys link sound levels with human response
• There is always a wide distribution of responses
• There is never a clear distinction between “acceptable” and “unacceptable” or “significant” and “not significant”

The same is true of vibration
Comparison of percentage highly annoyed for different sources
(Source: Miedema and Oudshoorn 2001)
Basics - sound

Annoyance distribution

Percentage of the population

Lower annoyance ←

Higher annoyance →

P12 (27)
Noise from fixed plant is assessed by comparing the $L_{A_{eq}}$ with a penalty added unless the noise is characterless against the background noise in $L_{A_{90}}$.

$L_{A_{90}}$ measures quiet moments e.g. between passing vehicles or aircraft.
Basics - sound

![Graph showing sound levels over time]

- $L_{A90}$

- Time, seconds vs. decibels

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P12 (29)
Basics – vibration (affecting people)

Vibration felt by the sense of touch is assessed using Vibration Dose Value (VDV)
Vibration affecting buildings is assessed using peak vibration velocity called “Peak Particle Velocity” or PPV.
Basics – vibration (heard as noise)

Groundborne noise is assessed using

maximum sound level, $L_{\text{Amax},S}$

where $S$ is the “slow” time weighting (1 second)
Government Policy

Noise Policy Statement for England aims:

Through the effective management and control of environmental, neighbour and neighbourhood noise within the context of Government policy on sustainable development:

• Avoid significant adverse impacts on health and quality of life
• Mitigate and minimise adverse effects on health and quality of life
• Where possible, contribute to the improvement of health and quality of life
Government Policy

Noise Policy Statement for England Explanatory

Note:

- Avoid effects above Significant Observed Adverse Effect Level (SOAEL)
- Mitigate and minimise effects between Lowest Observed Adverse Effect Level (LOAEL) and SOAEL.
- Proactively manage noise taking account the guiding principles of sustainable development

Not focussing solely on the noise impact without taking into account other related factors

Not possible to have a single objective noise-based measure that defines SOAEL that is applicable to all sources of noise in all situations. SOAEL is likely to be different for different noise sources, for different receptors and at different times.
Government Policy

Planning Practice Guidelines:

• Neither the NPSE nor the National Planning Policy Framework expects noise to be considered in isolation, separately from the economic, social and other environmental dimensions of proposed development.

• Above LOAEL consideration needs to be given to mitigating and minimising those effects (taking account of the economic and social benefits being derived from the activity causing the noise).

• Above SOAEL the planning process should be used to avoid this effect occurring, by use of appropriate mitigation such as by altering the design and layout. Such decisions should be made taking account of the economic and social benefit of the activity causing the noise, but it is undesirable for such exposure to be caused.

• Unacceptable effects should be prevented from occurring.
HS2 implementation of government policy

- Achieve Noise Policy aims
- Set LOAEL and SOAEL values having due regard to
  - Established practice
  - Research results
  - Guidance in national and international standards
  - Guidance from national and international agencies
  - Independent review by academic, industry and government employees on the Acoustics Review Group
# Operational airborne noise effect levels

<table>
<thead>
<tr>
<th>Time of day</th>
<th>Lowest Observed Adverse Effect Level (dB)</th>
<th>Significant Observed Adverse Effect Level (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day (0700 – 2300)</td>
<td>$50 , L_{\text{pAeq, 16hr}}$</td>
<td>$65 , L_{\text{pAeq, 16hr}}$</td>
</tr>
<tr>
<td>Night (2300 – 0700)</td>
<td>$40 , L_{\text{pAeq, 8hr}}$</td>
<td>$55 , L_{\text{pAeq, 8hr}}$</td>
</tr>
<tr>
<td>Night (2300 – 0700)</td>
<td>$60 , L_{\text{pAFMax}}$ (at the façade, from any nightly noise event)</td>
<td>$80 , L_{\text{pAFMax}}$ (at the façade, from more than 20 nightly train passbys), or $85 , L_{\text{pAFMax}}$ (at the façade, from 20 or fewer nightly train passbys)</td>
</tr>
</tbody>
</table>
## Operational groundborne noise and vibration effect levels

(including temporary railways)

<table>
<thead>
<tr>
<th>Ground-borne noise</th>
<th>Lowest Observed Adverse Effect Level</th>
<th>VDVday$[\text{m/s}^{1.75}]$</th>
<th>VDVnight$[\text{m/s}^{1.75}]$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$L_{pA\text{SMAX}}$ [dB]</td>
<td>35</td>
<td>0.2</td>
</tr>
<tr>
<td>Significant Observed Adverse Effect Level</td>
<td>$L_{pA\text{SMAX}}$ [dB]</td>
<td>45</td>
<td>0.1</td>
</tr>
<tr>
<td>Vibration</td>
<td>Lowest Observed Adverse Effect Level</td>
<td>VDVday$[\text{m/s}^{1.75}]$</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>VDVnight$[\text{m/s}^{1.75}]$</td>
<td>0.4</td>
<td></td>
</tr>
</tbody>
</table>
# Construction noise effect levels

<table>
<thead>
<tr>
<th>Day</th>
<th>Time (hours)</th>
<th>Averaging Period T</th>
<th>Lowest Observed Adverse Effect Level L_{P_Aeq,T} (dB)</th>
<th>Significant Observed Adverse Effect Level L_{P_Aeq,T} (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mondays to Fridays</td>
<td>0700 - 0800</td>
<td>1 hour</td>
<td>60</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>0800 - 1800</td>
<td>10 hours</td>
<td>65</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td>1800 - 1900</td>
<td>1 hour</td>
<td>60</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>1900 – 2200</td>
<td>1 hour</td>
<td>55</td>
<td>65</td>
</tr>
<tr>
<td>Saturdays</td>
<td>0700 - 0800</td>
<td>1 hour</td>
<td>60</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>0800 - 1300</td>
<td>5 hours</td>
<td>65</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td>1300 - 1400</td>
<td>1 hour</td>
<td>60</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>1400 – 2200</td>
<td>1 hour</td>
<td>55</td>
<td>65</td>
</tr>
<tr>
<td>Sundays &amp; Public Holidays</td>
<td>0700 – 2200</td>
<td>1 hour</td>
<td>55</td>
<td>65</td>
</tr>
<tr>
<td>Any night</td>
<td>2200 – 0700</td>
<td>1 hour</td>
<td>45</td>
<td>55</td>
</tr>
</tbody>
</table>
Fixed plant noise control

Under BS 4142:

If the “rating level” ($L_{A_{eq}}$ plus a penalty of up to 9dB for acoustic features such as tonality or impulsivity) minus $L_{A_{90}}$ is

around +10 or more: likely to be an indication of a significant adverse impact
around +5: likely to be an indication of an adverse impact
0 or less: likely to be an indication of a low impact
Operational Noise – contribution of sources

Sound sources at 25 metres from the track

- Total passby sound (HS2 train on HS2 infrastructure)
- Rolling Sound
- Body Aerodynamic Sound
- Power/traction/aux
- Pantograph Sound

Graph showing the contribution of various noise sources at different train speeds.
Mitigation – Operational Noise

Operational noise will be mitigated by

- Train design
- Noise barriers
- Noise insulation where eligible
Mitigation – Train design

Current European TSI compliant trains do not have pantographs / wells designed to minimise aerodynamic noise (TGV / Eurostar)

Current Asian HS trains do have pantographs / wells designed to minimise aerodynamic noise (Shinkansen N700)
Mitigation – Noise barriers
Mitigation – Noise barriers

Illustration of path difference \((a + b - c)\) introduced by a barrier
Mitigation – Micro pressure waves

HS2 “porous portal”
Mitigation – Operational Vibration

Operational vibration will be mitigated by

- Train design and maintenance
- Track design and maintenance
Mitigation – Operational groundborne noise

Operational groundborne noise will be mitigated by

- Track design and maintenance
- Continuous welded rail
- Resilient rail support
Mitigation – Track design

- Proven optimised track solutions – e.g. HS1 London Tunnels slab track
Mitigation – Construction Noise

Construction noise will be mitigated by

- Up-to-date methods of working
- Modern plant
- Noise barriers
- Noise enclosures
- Monitoring and management

All subject to Section 61 consent

- Noise insulation/temporary rehousing
Mitigation – Construction Vibration

Construction vibration will be mitigated by

- methods of working
- monitoring and management

All subject to Section 61 consent
HS2 Information Papers

E20 Control of airborne noise from altered roads and the operational railway

E21 Control of ground-borne noise and vibration from the operation of temporary and permanent railways

E22 Control of noise from the operation of stationary systems

E23 Control of construction noise and vibration

F4 Operational Noise and Vibration Monitoring Framework