HS2

Sound, Noise and Vibration

An explanation

Rupert Thornely-Taylor
March 2018
Outline of Presentation

What sound is - sources, and ways in which is it transmitted from source to receiver

What vibration is - sources, and ways in which is it 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
Basics – what vibration is

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.
Basics – what vibration is

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 subjective loudness

Every 10 dB *decrease* is about a *halving* of subjective loudness
Basics - sound

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 lawn mower</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 lawn mower</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 $L_{A_{max}}$

$L_{A_{max}}$ levels are presented in the tables in Volume 5 of the Environmental Statement. These are $L_{A_{F_{max}}}$ 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.

\[ L_{\text{eq,T}} \quad \text{(or } L_{\text{Aeq,T}}) \]

\[ T = \text{time period} \]

\( L_{\text{Aeq,T}} \) levels are presented both in the tables in Volume 5 of the Environmental Statement and also plotted as contours for the time periods (0700-2300) and (2300-0700).
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...
$L_{Aeq}$ is no ordinary average...
$L_{Aeq}$ 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 +10dB
Basics - sound

Environmental Indices based on $L_{Aeq}$

Noise in the day, evening and night periods has different effects, and for purposes such as noise mapping this is taken into account by calculating $L_{Aeq}$ separately for the three periods as annual energy - average outdoor noise levels:

- $L_{\text{day}}$ 0700-1900
- $L_{\text{evening}}$ 1900-2300
- $L_{\text{night}}$ 2300-0700

and combining these into one 24-hour long term index.
Basics - sound

Day-Evening-Night Level $L_{den}$

Allowance is made for greater noise sensitivity at night, and to a lesser extent in the evening.

Night noise is treated as if it were 10 dB higher than the physical level.

Evening noise is treated as if it were 5 dB higher than the physical level.
Basics - sound

Day-Evening-Night Level $L_{den}$

$L_{day}$ is then combined with $L_{evening} + 5$ dB and $L_{night} + 10$ dB to calculate $L_{den}$

The difference between $L_{den}$ and $L_{Aeq(0700-2300)}$ depends on the relative amounts of day, evening and night noise.

For HS2 $L_{den}$ is less than 1 dB greater in numerical level than $L_{Aeq}$, so for practical purposes, $L_{Aeq}$ levels can be read as $L_{den}$ levels.
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
Basics - sound

Normal Distribution of annoyance responses at a set noise level

Degree of annoyance →

Percentage of the population →
Basics - sound

Cumulative distribution of annoyance responses at a set noise level

- Percentage at least annoyed to a set degree
- Noise level

HOC/10001/0031
Basics - sound

Cumulative distribution of annoyance responses at a set noise level

Percentage at least annoyed to a set degree

Noise level
Basics - sound

Noise from fixed plant is assessed by comparing the $L_{Aeq}$ with a penalty added unless the noise is characterless against the background noise in $L_{A90}$.

$L_{A90}$ measures quiet moments e.g. between passing vehicles or aircraft.
Basics - sound
Basics – vibration (affecting people)

Vibration felt by the sense of touch is assessed using Vibration Dose Value (VDV)
Basics – vibration (affecting buildings)

Vibration affecting buildings is assessed using peak vibration velocity called “Peak Particle Velocity” or PPV.
Groundborne noise is assessed using maximum sound level, $L_{A_{\text{max, } S}}$

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 Guidance:

• 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
HS2 implementation of government policy

• DfT Transport analysis guidance: WebTAG
• Magnitude of railway noise effect (adverse or beneficial) is calculated using WebTAG
• WebTAG monetises the health effect cause by a change in noise (day and night)
• The WebTAG results are reported for the population in the health chapter of the EIA
• WebTAG has also been used at a local level to calculate the monetised value of noise control measures
### 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 $L_{pA_{eq, 16hr}}$</td>
<td>65 $L_{pA_{eq, 16hr}}$</td>
</tr>
<tr>
<td>Night (2300 – 0700)</td>
<td>40 $L_{pA_{eq, 8hr}}$</td>
<td>55 $L_{pA_{eq, 8hr}}$</td>
</tr>
<tr>
<td>Night (2300 – 0700)</td>
<td>60 $L_{pA_{FMax}}$ (at the façade, from any nightly noise event)</td>
<td>80 $L_{pA_{FMax}}$ (at the façade, from more than 20 nightly train passbys), or 85 $L_{pA_{FMax}}$ (at the façade, from 20 or fewer nightly train passbys)</td>
</tr>
</tbody>
</table>
Operational airborne noise effect levels

Table 1.1: Implied notation for assessment results

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>Denotes a major impact at a residential building – a change is of &gt;10 dB</td>
</tr>
<tr>
<td>Orange</td>
<td>Denotes a moderate impact at a residential building – a change is of 5-10 dB</td>
</tr>
<tr>
<td>Yellow</td>
<td>Denotes a minor impact at a residential building – a change is of 3-5 dB</td>
</tr>
<tr>
<td>Pink</td>
<td>Where the significant effect column is marked, then a significant effect is identified at the reference group of dwelling; or individual residential or non-residential receptor</td>
</tr>
</tbody>
</table>

Day: L_{eq,day}, 0600-2200

Night: L_{eq,night}, 2200-0600
Operational airborne noise effect levels
Operational airborne noise effect levels
### Operational airborne noise effect levels

<table>
<thead>
<tr>
<th>Assessment location</th>
<th>Impact criteria</th>
<th>Significance criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ref</td>
<td>Area represented</td>
<td>Proposed Scheme only (year 15 traffic)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Day e</td>
</tr>
<tr>
<td>11125</td>
<td>Ravensbank Farm, Hopton</td>
<td>28</td>
</tr>
<tr>
<td>11116</td>
<td>Kings Drive, Hopton</td>
<td>52</td>
</tr>
<tr>
<td>11127</td>
<td>Within Lane, Hopton</td>
<td>61</td>
</tr>
<tr>
<td>11127</td>
<td>Within Lane, Hopton</td>
<td>47</td>
</tr>
<tr>
<td>11126</td>
<td>Hopton Hill Lane, Hopton</td>
<td>40</td>
</tr>
<tr>
<td>11126</td>
<td>Hopton Hill Lane, Hopton</td>
<td>53</td>
</tr>
<tr>
<td>11123</td>
<td>Orchard Caravan Site, Hopton</td>
<td>46</td>
</tr>
<tr>
<td>11123</td>
<td>Lower Lane, Hopton</td>
<td>56</td>
</tr>
<tr>
<td>11123</td>
<td>Within Lane, Hopton</td>
<td>53</td>
</tr>
<tr>
<td>11124</td>
<td>Within Lane, Hopton</td>
<td>57</td>
</tr>
<tr>
<td>11125</td>
<td>Ravensbank Farm, Hopton</td>
<td>38</td>
</tr>
<tr>
<td>11126</td>
<td>Lower Lane, Hopton</td>
<td>55</td>
</tr>
<tr>
<td>11127</td>
<td>Within Lane, Hopton</td>
<td>43</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>L_{PASM} \text{ [dB]}</th>
<th>35</th>
</tr>
</thead>
<tbody>
<tr>
<td>Significant Observed Adverse Effect Level</td>
<td>L_{PASM} \text{ [dB]}</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td>Vibration</td>
<td>Lowest Observed Adverse Effect Level</td>
<td>VDV_{day}[m/s^{1.75}]</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>VDV_{night}[m/s^{1.75}]</td>
<td>0.1</td>
</tr>
<tr>
<td>Significant Observed Adverse Effect Level</td>
<td>VDV_{day}[m/s^{1.75}]</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>VDV_{night}[m/s^{1.75}]</td>
<td>0.4</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 $L_{pAeq,T}$ (dB)</th>
<th>Significant Observed Adverse Effect Level $L_{pAeq,T}$ (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” (\(L_{\text{Aeq}}\) plus a penalty of up to 9dB for acoustic features such as tonality or impulsivity) minus \(L_{A90}\) 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
Mitigation – Operational Noise

Operational noise mitigation measures will include:

- Train and track design
- Noise barriers
- Noise insulation where eligible
Operational Noise – mitigated railway

Hopton - Assessment location ref.: 12129
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 – Micropressure waves

When a train enters a tunnel at high speed, there is a sudden rise in pressure like the effect of a piston in a tube.

A special kind of sound wave occurs, in which the compressed crest of the wave travels faster than the trough (because the compressed air is warmer), causing a steep rise in pressure as the travelling wave passes any fixed point.

This wave travels ahead about three times faster than the train, and when it reaches the tunnel exit portal, some is reflected and some is emitted to the outside world as a boom-like sound.
Mitigation – Micropressure waves

The first wave arrives well before the train emerges, and is followed by smaller waves that have been reflected at both ends of the tunnel and also emerge as weakened copies of the first wave.

The prime means of mitigation is to make the initial rise in pressure on the train’s entry to the tunnel smaller and less steep, and this is done by constructing a “porous portal”, which does two things:

It is tapered so the entrance to it is considerably larger than the tunnel and it has progressively smaller openings in its sides to allow some air to escape before the train reaches the tunnel “eye”.


Mitigation – Micro-pressure waves
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
Standard Track design
Mitigation - Track design

Proven optimised track solutions
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

E9  Control of airborne noise
E10 Control of ground-borne noise and vibration from the operation of temporary and permanent railways
E11 Control of noise from the operation of stationary systems
E12 Operational Noise and Vibration Monitoring Framework
E13 Control of construction noise and vibration