Status: TCRP Project D-12
Ground-Borne Noise and Vibration in Buildings Caused by Rail Transit

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Ground Vibration

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Shake, Rattle, and Rumble

- Perceptible mechanical motion (shaking).
- Noise caused by vibrating items in household (rattling).
- Secondary noise radiated from vibrating room surfaces (rumbling).
Project Issues

Are we looking at the right things?
Are we using the right weighting function?
Are we applying the criteria at the best location?
How much variation is there in people’s response?
How much vibration is too much?
Background

Prior to 1970’s vibration specifications rarely seen.

Experiences in Toronto in the late 60’s and early 70’s led to increased concern.

Early results suggested vibration levels below 75 VdB would generate few complaints.
Dosage-Effect Function

Percent Population Highly Annoyed by Rail Vibration vs. Physical Measure of Ground Vibration.

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Project Tasks

PHASE 1
- Literature Review
- Survey North American Rail Transit Systems
- Identify Transit Systems for Field Studies
- Develop Field Survey and Measurement Program

PHASE 2
- Field Tests – Interviews and Measurements
- Develop Human Response Curve

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Transit Agencies Survey

Purpose was to obtain impression of whether vibration is a significant problem.
Tried to balance amount of information and response rate.
Contacted APTA members at various agencies first by telephone, then e-mailed survey to appropriate persons.
Survey Results

- Overall response rate 55%.
- 50% reported no problems or complaints at all.
- Only 2 systems reported having major problems.
- Most vibration problems tended to be focused, rather than system-wide.
### Survey Results: Complaints

<table>
<thead>
<tr>
<th>Category</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zero Complaints</td>
<td>17</td>
</tr>
<tr>
<td>1 to 5 Complaints</td>
<td>10</td>
</tr>
<tr>
<td>6-20 Complaints</td>
<td>2</td>
</tr>
<tr>
<td>50+ Complaints</td>
<td>1</td>
</tr>
</tbody>
</table>
Literature Review: Objectives

- Examine International Standards
  - Evaluation Methods
  - Vibration Limits and Guidelines

- Review Published Literature
  - Laboratory Studies
  - Field Work/Social Surveys
Vibration Descriptors in Use

- Root mean square acceleration and velocity (rms)
- Weighted vibration, various weighting curves
- Root mean quad weighted vibration (rmq)
- Fourth power vibration dose (m/s^{1.75})
- Imperial and metric units
- Decibels with different reference values
Acceleration Weighting Curves

Vibration Weighting Curves (Acceleration)

Frequency Weighting, dB

Frequency, Hz

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Normalized Velocity Weighting Curves

**Normalized Vibration Weighting Curves (Velocity)**

- Frequency Weighting, dB
- Frequency, Hz

- BS(xy)
- Wb(xy)
- ANSI
- Wm
- Wk(z)
- BS(z)

Critical frequency range for ground vibration

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Comparison of Vibration Standards

Vibration Threshold, VdB

- U.S.
- Britain
- Sweden
- Norway
- Denmark
- Germany & Belgium
- Italy
- Australia
- Japan

- Daytime
- Nighttime

FTA Limit for Residential Land Uses

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Literature Review: Related Research

β Laboratory Studies
- Thresholds of Perception and Equal Annoyance Contours
- Annoyance vs. Vibration Levels
- Combined Effects of Noise and Vibration

β Social Surveys
Annoyance vs. Frequency

Equal Annoyance

Perception

ANSI Curve

Velocity Level, dB re 1μm/sec

Frequency, Hz

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Surveys of Community Response 1

Scotland (Woodroof & Griffin, 1986)

459 interviews, 160 of whom noticed vibration

52 24-hour vibration measurements

Conclusion: “...vibration is among the least annoying aspects of a railway’s presence in a neighborhood.”
Surveys of Community Response 2

Sweden (Öhrström, 1997)

- Obtained from buildings where inhabitants had complained about vibrations
- Much higher vibration levels than in Scotland
- Wide variation in exposure-effect relationships
Surveys of Community Response 3

Norway (Klaeboe et al, 2003)

- 1500 telephone interviews
- Estimates of exposure
- Exposures ranging from below perception to 100 VdB
Annoyance vs. Vibration Level
(Klaeboe et al, 2003)

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Phase 2 Testing

- Letter to GM requesting assistance
- Target is 2,000 telephone interviews in 20 neighborhoods
- Measurements inside 120 residences
- Standardized field procedures
- Record directly to computer files
- Computerized data analysis
- Results stored directly into database
### Potential Test Systems

<table>
<thead>
<tr>
<th>Commuter Rail</th>
<th>Light Rail</th>
<th>Rapid Transit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metrolink (LA)</td>
<td>Sacramento</td>
<td>15. BART</td>
</tr>
<tr>
<td>Caltrain</td>
<td>LA Blue Line</td>
<td>16. CTA</td>
</tr>
<tr>
<td>Chicago METRA</td>
<td>10. DART (Dallas)</td>
<td>17. TTC</td>
</tr>
<tr>
<td>MBTA</td>
<td>11. SF MUNI</td>
<td>18. NYCTA</td>
</tr>
<tr>
<td>Long Island RR</td>
<td>12. San Jose</td>
<td>19. WMATA</td>
</tr>
<tr>
<td>Metro North</td>
<td>13. Hudson Bergen</td>
<td>20. MBTA</td>
</tr>
<tr>
<td>GO Transit</td>
<td>14. MBTA Green Line</td>
<td>21. SEPTA</td>
</tr>
</tbody>
</table>
## US Standards

<table>
<thead>
<tr>
<th>Land Use Category</th>
<th>Vibration</th>
<th>Ground-Borne Noise</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Frequent</td>
<td>In-frequent</td>
</tr>
<tr>
<td>Category 1: Buildings where low ambient vibration is essential for interior operations.</td>
<td>65 VdB</td>
<td>65 VdB</td>
</tr>
<tr>
<td>Category 2: Residences and buildings where people normally sleep.</td>
<td>72 VdB</td>
<td>80 VdB</td>
</tr>
<tr>
<td>Category 3: Institutional land uses with primarily daytime use.</td>
<td>75 VdB</td>
<td>83 VdB</td>
</tr>
</tbody>
</table>

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Current Issues

- Standards Currently in Use
- Experience of North American Transit Systems
- Field Survey Procedures
  - Telephone Interviews
  - Where to measure noise/vibration
- How to Analyze Data
## Survey Results

<table>
<thead>
<tr>
<th>Type</th>
<th>Number with Minor Problems</th>
<th>Number with Major Problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light Rail</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>Heavy Rail</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Commuter Rail</td>
<td>5</td>
<td>0</td>
</tr>
</tbody>
</table>

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