Transit Noise and Vibration Overview

May 12 and 13, 2015
Workshop Agenda

• Welcome and Introductions
• Workshop Goals and Outline
• Noise
• Questions/Answers
• Workshop Break
• Vibration
• Questions/Answers
Workshop Goals

• The goals of the workshop are to provide stakeholders with information on:
  ▪ How Federal Transit Administration (FTA) guidance is used to assess and mitigate transit noise and vibration
  ▪ What are the basics of noise and vibration
  ▪ How are noise and vibration measured and modeled
  ▪ What are noise and vibration impacts
  ▪ What are the criteria for determining impacts
  ▪ What mitigation options are available

• Participants will be better prepared to review and understand the information in the Final Environmental Impact Statement (FEIS)
Workshop Outline

• Noise
  ▪ Basics
  ▪ Criteria
  ▪ Assessment Methods
  ▪ Mitigation Options
  ▪ Construction

• Vibration
  ▪ Basics
  ▪ Criteria
  ▪ Assessment Methods
  ▪ Mitigation Options
  ▪ Construction
Variables of Sound

• Amplitude (loudness)
• Frequency (pitch)
• Time pattern
## Loudness

- **Sound**: Rapid fluctuations in atmospheric pressure
- **Sound pressure level (SPL)**: Ratio of the measured pressure to a reference pressure
- **Decibels (dB)**: Unit of SPL, uses a logarithmic scale

<table>
<thead>
<tr>
<th>Sound Pressure Level (dB)</th>
<th>Sound Pressure (micro-pascals)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>60</td>
<td>20,000</td>
</tr>
<tr>
<td>120</td>
<td>20,000,000</td>
</tr>
</tbody>
</table>
Frequency: Pitch

• Under normal conditions the speed of sound is approximately 1000 feet per second

For a frequency of 1000 Hz, the wavelength is 1 foot
For a frequency of 500 Hz, the wavelength is 2 foot
For a frequency of 100 Hz, the wavelength is 10 foot
Time Pattern

- Steady
- Intermittent
- Transient
Defining Transit Noise

• A-Weighted Sound Level: dBA
  ▪ Instantaneous sound level

• Maximum Noise Level: \(L_{\text{max}}\)
  ▪ Loudest noise level for a specific event

• Equivalent Sound Level: \(L_{\text{eq}}\)
  ▪ Cumulative noise over a period of time
  ▪ Describes community response to noise

• Day-Night Sound Level: \(L_{\text{dn}}\)
  ▪ The most widely used environmental noise metric
Maximum Noise Level ($L_{\text{max}}$)

![Graph 1](#)

$L_{\text{max}} = 102.5 \text{ dBA}$

![Graph 2](#)

$L_{\text{max}} = 102.5 \text{ dBA}$
Equivalent Sound Level ($L_{eq}/L_{dn}$)

- Cumulative noise exposure
- Equivalent to changing noise over time period
- $L_{dn}$ is the descriptor for 24-hour exposure
- Defined as 24-hour $L_{eq}$ with 10 decibel penalty applied to nighttime noise
Adding Decibels

• How to we add two sources of noise?
• Decibels are on a logarithmic scale, so direct addition does not work
• We add the energy of two sources
• Easy way to add decibels

<table>
<thead>
<tr>
<th>When two decibel values differ by:</th>
<th>Add to the higher value:</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 or 1 dB</td>
<td>3 dB</td>
</tr>
<tr>
<td>2 or 3 dB</td>
<td>2 dB</td>
</tr>
<tr>
<td>4 to 8 dB</td>
<td>1 dB</td>
</tr>
<tr>
<td>9 dB or more</td>
<td>0 dB</td>
</tr>
</tbody>
</table>
Source-Path-Receiver
Sources of Transit Noise

• LRT/Streetcars
  ▪ Wheel/rail interaction
  ▪ Propulsion system
  ▪ Wheel squeal
  ▪ Horns and bells

• Commuter rail vehicles
  ▪ Diesel engine, exhaust & fans
  ▪ Wheel/rail interaction
  ▪ Horns and bells

• Stations
  ▪ Automobile and bus traffic
  ▪ Vehicle idling
  ▪ P.A. systems

• Buses
  ▪ Diesel engine, exhaust & fans
  ▪ Traction motors (electric buses)
  ▪ Tire/roadway

• Maintenance/storage yards
  ▪ Vehicle activity
  ▪ Signal horns and bells
  ▪ P.A. systems
  ▪ Impact tools
  ▪ Vehicle washers/driers
Path Factors for Noise

- Divergence
- Atmospheric Conditions
- Ground Attenuation
- Barriers
## Typical Noise Levels

<table>
<thead>
<tr>
<th>Typical Environments</th>
<th>Ldn dBA</th>
<th>Transit/Freight Rail Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient close to Urban Freeways or Major Airport</td>
<td>85</td>
<td>Freight Rail with Horn at 20 mph 2 Loco + 50 Cars 15 Day, 9 Night</td>
</tr>
<tr>
<td>Urban Ambient</td>
<td>70</td>
<td>Freight Rail at 20 mph 2 Loco + 50 Cars 15 Day, 9 Night</td>
</tr>
<tr>
<td>Suburban Ambient</td>
<td>65</td>
<td>Rail Transit at 40 mph 6-car Trains 300 Day, 18 Night</td>
</tr>
<tr>
<td>Rural Ambient</td>
<td>55</td>
<td>Rail Transit at 20 mph 2-car Trains 300 Day, 18 Night</td>
</tr>
<tr>
<td>Wilderness Ambient</td>
<td>35</td>
<td></td>
</tr>
</tbody>
</table>
FTA Noise Impact Criteria

![Diagram showing noise impact criteria]

- **NO IMPACT**
- **MODERATE IMPACT**
- **SEVERE IMPACT**

Note:
Noise exposure is in terms of $L_{eq}$ (h) for Category 1 and 3 land uses, $L_{dn}$ for Category 2 land uses.
FTA Noise Impact Criteria

Note:
Noise exposure is in terms of $L_{eq}$ (h) for Category 1 land uses, $L_{dn}$ for Category 2 land uses.
## Land Use Categories

<table>
<thead>
<tr>
<th>Land Use Category</th>
<th>Noise Metric (dBA)</th>
<th>Description of Land Use Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Outdoor $L_{eq}(h)^*$</td>
<td>Tracts of land where quiet is an essential element in their intended purpose. This category includes lands set aside for serenity and quiet, and such land uses as outdoor amphitheaters and concert pavilions, as well as National Historic Landmarks with significant outdoor use. Also included are recording studios and concert halls.</td>
</tr>
<tr>
<td>2</td>
<td>Outdoor $L_{dn}$</td>
<td>Residences and buildings where people normally sleep. This category includes homes, hospitals and hotels where a nighttime sensitivity to noise is assumed to be of utmost importance.</td>
</tr>
<tr>
<td>3</td>
<td>Outdoor $L_{eq}(h)^*$</td>
<td>Institutional land uses with primarily daytime and evening use. This category includes schools, libraries, theaters, and churches where it is important to avoid interference with such activities as speech, meditation and concentration on reading material. Places for meditation or study associated with cemeteries, monuments, museums, campgrounds and recreational facilities can also be considered to be in this category. Certain historical sites and parks are also included.</td>
</tr>
</tbody>
</table>

* $L_{eq}$ for the noisiest hour of transit-related activity during hours of noise sensitivity.
Noise Assessment Types

• Screening Assessment
  ▪ Identify areas of potential impact
  ▪ Estimate distances beyond which no impacts are likely
  ▪ If potential for impact exists, conduct a General Assessment
  ▪ If potential for impact does not exist, no further assessment necessary

• General Assessment
  ▪ Next step after Screening
  ▪ All that is needed for many smaller transit projects
  ▪ Used to evaluate alternatives
  ▪ Identifies locations where mitigation may be needed
  ▪ Use FTA noise assessment spreadsheet
Noise Assessment Types

• Detailed Assessment
  ▪ Site-specific analysis for mitigation
  ▪ Detailed project information
  ▪ FEIS, preliminary engineering, design
  ▪ Items included:
    o Grade-crossing noise
    o Curve squeal
    o Propagation characteristics
    o Ground effects
    o Shielding by buildings and barriers
    o Crossovers and special trackwork
Noise Assessment Inputs

- Number of cars per train
- Number of trains per hour
- Speed
- Hours of operation
- Source noise level
- Path factors
- Track type
- Distance
Combined Transit and Roadway Projects

• Two projects assessed independently
  ▪ Blue Line LRT Extension
  ▪ West Broadway Avenue

• Combined effects of both projects (cumulative effects) will be documented in the FEIS for the Blue Line LRT
  ▪ Will include combined LRT and traffic noise
  ▪ Mitigation, if required, will be designed for both projects
FTA Noise Mitigation Policy

• No Impact
  ▪ Mitigation generally not required

• Moderate Impact
  ▪ Mitigation to be considered and adopted, if reasonable

• Severe Impact
  ▪ Seek alternatives to avoid impacts
  ▪ If not practical to avoid, mitigation must be considered
Noise Mitigation

• Source
  ▪ Vehicle noise specs
  ▪ Lubrication/friction modification
  ▪ Wheel truing/rail grinding
  ▪ Vehicle body treatments
  ▪ Wheel treatments
  ▪ Crossovers
  ▪ Quiet zones
  ▪ Wayside horns

• Path
  ▪ Barriers
  ▪ Berms

• Receiver
  ▪ Sound insulation
Construction Noise Sources

- Diesel engines: excavators, backhoes, dozers
- Impacts: jackhammers, pile drivers, hoe rams
- Backup alarms
## Construction Typical Noise Levels

<table>
<thead>
<tr>
<th>Typical Noise Levels at 50 ft (dBA)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Backhoe</td>
<td>80</td>
</tr>
<tr>
<td>Concrete Truck</td>
<td>88</td>
</tr>
<tr>
<td>Excavator</td>
<td>82</td>
</tr>
<tr>
<td>Hoe-Ram</td>
<td>95</td>
</tr>
<tr>
<td>Jackhammer</td>
<td>88</td>
</tr>
<tr>
<td>Pickup Truck</td>
<td>60</td>
</tr>
<tr>
<td>Pile Driver (Impact)</td>
<td>101</td>
</tr>
</tbody>
</table>
Mitigation of Construction Noise

• Design considerations and project layout

• Sequence of operations

• Alternative construction methods
Common Themes: Noise

- Hearing a noise is not necessarily an impact
- Noise barriers will not increase noise levels
- Leq/Ldn is not an “average” and does not present “reduced” noise levels: it is a cumulative noise level
- Active noise control does not work outside
- Speed reductions are not acceptable mitigation
- Trees and vegetation do not work as noise mitigation
Defining Transit Vibration

• Ground-borne vibration: the shaking motion of a building
• Ground-borne noise: the sound generated by shaking of walls, ceilings, floors.
• Use vibration decibels (VdB) to describe vibration
• Use A-weighted sound level (dBA) to describe ground-borne noise
Vibration Source-Path-Receiver

Diagram showing the propagation of vibration through different soil layers and resulting in structural vibration and radiated sound.
Components of Transit Vibration

• **Source**
  - Vehicle suspension
  - Wheel/track condition
  - Track support system
  - Speed
  - Transit structure

• **Path**
  - Soil type/layering
  - Rock layers

• **Receiver**
  - Foundation type
  - Building construction
Transit Vibration

![Graph showing RMS velocity level in microinches/sec as a function of distance from track centerline in feet. Three lines represent different types of vehicles: Locomotive Powered Passenger or Freight (50 mph), Rapid Transit or Light Rail Vehicles (50 mph), and Rubber-Tired Vehicles (30 mph). The graph includes a note referring to diagonal distance for underground systems.](image)
## Typical Vibration Levels

<table>
<thead>
<tr>
<th>Human/Structural Response</th>
<th>Vibration Level (VdB)</th>
<th>Transit/Freight Rail Sources at 50 ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Threshold, minor cosmetic damage to fragile buildings</td>
<td>100</td>
<td>Blasting from construction projects</td>
</tr>
<tr>
<td>Difficulty with tasks such as reading a CRT screen</td>
<td>90</td>
<td>Bulldozers and other heavy-tracked construction equipment</td>
</tr>
<tr>
<td>Residential annoyance, infrequent events (e.g., commuter rail)</td>
<td>80</td>
<td>Freight rail, upper range</td>
</tr>
<tr>
<td>Residential annoyance, frequent events (e.g., rapid transit)</td>
<td>70</td>
<td>Commuter rail, upper range</td>
</tr>
<tr>
<td>Limit for vibration sensitive equipment. Approx. threshold for human perception of vibration</td>
<td>60</td>
<td>Rapid transit, upper range</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>Rapid transit, typical</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bus or truck over bump</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bus or truck, typical</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Typical background vibration</td>
</tr>
<tr>
<td>Land Use Category</td>
<td>GBV Impact Levels (VdB)</td>
<td></td>
</tr>
<tr>
<td>---------------------------------------------------------------------------------</td>
<td>-------------------------</td>
<td>---</td>
</tr>
<tr>
<td></td>
<td>Frequent Events</td>
<td>Occasional Events</td>
</tr>
<tr>
<td>Category 1: Buildings where vibration would interfere with interior operations.</td>
<td>65</td>
<td>65</td>
</tr>
<tr>
<td>Category 2: Residences and buildings where people normally sleep.</td>
<td>72</td>
<td>75</td>
</tr>
<tr>
<td>Category 3: Institutional land uses with primarily daytime use.</td>
<td>75</td>
<td>78</td>
</tr>
</tbody>
</table>
Vibration Criteria: Special Buildings

<table>
<thead>
<tr>
<th>Type of Building or Room</th>
<th>GBV Impact Levels (VdB)</th>
<th>GBN Impact Levels (dBA)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Frequent Events</td>
<td>Occasional or Infrequent Events</td>
</tr>
<tr>
<td>Concert Halls</td>
<td>65</td>
<td>65</td>
</tr>
<tr>
<td>TV Studios</td>
<td>65</td>
<td>65</td>
</tr>
<tr>
<td>Recording Studios</td>
<td>65</td>
<td>65</td>
</tr>
<tr>
<td>Auditoriums</td>
<td>72</td>
<td>80</td>
</tr>
<tr>
<td>Theaters</td>
<td>72</td>
<td>80</td>
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Vibration Assessment Types

• Screening Assessment
  ▪ Identify areas of potential impact
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• General Assessment
  ▪ Next step after Screening
  ▪ All that is needed for many smaller transit projects
  ▪ Used to evaluate alternatives
  ▪ Identifies locations where mitigation may be needed
  ▪ Use FTA general assessment methodology
Vibration Assessment Types

• Detailed Assessment
  ▪ Site-specific analysis for mitigation
  ▪ Use for highly sensitive sites
  ▪ FEIS, preliminary engineering, design
  ▪ Complex analytical methods
  ▪ Special instrumentation
  ▪ Detailed project information
    ○ Track type
    ○ Vehicle force input
    ○ Ground propagation response
    ○ Frequency distribution of vibration
    ○ Crossovers and special trackwork
Vibration Assessment Inputs

- Speed
- Number of trains per day
- Source Vibration level
- Soil characteristics
- Track Type
- Distance
- Building foundation
Vibration Mitigation

• **Source**
  - Special trackwork
  - Wheel truing/rail grinding
  - Vehicle specifications

• **Path**
  - Track support systems
    - Resilient track fasteners
    - Ballast mats
    - Resiliently supported ties
    - TDA underlayment
    - Floating slabs
  - Trenches
  - Buffer zones

• **Receiver**
  - Building modifications
Construction Vibration Sources

- Compactors/vibratory rollers
- Heavy equipment movement
- Pile driving
Construction Vibration Effects

- Damage vs. annoyance
  - Peak Particle Velocity (PPV) used in damage assessment
    - Typically measured for blasting and other high vibration events
    - Related to the stresses experienced by buildings
  - Velocity level (VdB) used in annoyance assessment
    - A measure of how humans respond to vibration in their environment
# Construction Vibration Annoyance Criteria

<table>
<thead>
<tr>
<th>Land Use Category</th>
<th>GBV Impact Levels (VdB)</th>
<th>GBN Impact Levels (dBA)</th>
</tr>
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<tbody>
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<td></td>
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<td>75</td>
<td>78</td>
</tr>
</tbody>
</table>
## Construction Vibration Damage Criteria

<table>
<thead>
<tr>
<th>Structural Category</th>
<th>PPV Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Reinforced concrete and steel structures (without plaster) such as industrial buildings, bridges, masts, retaining walls, and unburied pipelines. Underground structures such as caverns, tunnels, galleries, lined and unlined.</td>
<td>0.5 in/sec</td>
</tr>
<tr>
<td>II. Buildings with concrete floors and basement walls and above-grade walls of concrete brick or ashlar masonry, ashlar retaining walls, and buried pipelines. Underground structures such as caverns, tunnels, and galleries, with masonry lining.</td>
<td>0.3 in/sec</td>
</tr>
<tr>
<td>III. Buildings with concrete basement floors and walls, above-grade masonry walls, and timber joist floors.</td>
<td>0.2 in/sec</td>
</tr>
<tr>
<td>IV. Buildings which are particularly vulnerable or worth protecting.</td>
<td>0.12 in/sec</td>
</tr>
</tbody>
</table>
Construction Vibration Mitigation

- Design considerations and project layout
- Sequence of operations
- Alternative construction operations
Common Themes: Vibration

- Transit vibration does not generate high enough levels to cause damage to typical houses
- The threshold for human perception is several orders of magnitude below even the most stringent damage criteria
- Most superficial cracking is due to settlement, changes in the water table and freeze/thaw cycles
- Construction vibration has the potential to cause damage, but only at very close distances for activities such as pile driving
- Trenches are impractical and usually not effective
More Information

Website: BlueLineExt.org
Email: BlueLineExt@metrotransit.org
Twitter: @BlueLineExt