Evaluation of Vibration Mitigation Measures to Control Groundborne Noise from Underground Transit

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Outline

- Introduction
- Brief review of the projection model
- Results of the analysis and preliminary recommendations
- Review of the additional analysis using a theoretical model
- Conclusions
Introduction

- Silicon Valley Rapid Transit Project (SVRTP)
- Extension from Fremont to San José, CA
- Heavy rail System
- Currently finishing RDEIR
- WIA participate during Preliminary Engineering (PE)
- PE ended during summer of 2006
- 26 Km extension project
- Construction cost of $4.7 Billion (2005 dollar)
- 8.6 Km underground
  - Double bored tunnel (6,900 m)
  - Cut and cover (at 3 stations - 990 m)
- Design speed: 72 Km/h and 105 Km/h
- Base alignment + 2 options at Coyote Creek
Project Timeline

- Preliminary evaluation of impacts and mitigation options
  - Mitigation options considered:
    - Highly resilient direct fixation fastener (HRDF)
    - Rail suspension fastener (RSF)
    - Isolated slab track (IST)
    - Floating slab track (FST)

- Additional study of mitigation options
  - Resiliently supported tie (RST)
  - High attenuation RST (HARST)
Projection Model

- Methodology follows the FTA procedure for detailed analysis
- Vibration: three main components plus adjustments

\[ L_v = L_{fd} + TM_{lineal} + C_{building} + \text{Adjust.} + \text{Design Factor} \]

- Groundborne noise

\[ L_A = L_v + K_{rad} + K_{A-wt} \]
- **Force Density Level** ($L_{fd}$)
  - Characteristic of the system (vehicle)
  - Track type (ballast, direct fixation track, etc)
  - Speed

![Graph showing Force Density Level (Lfd) vs. Frequency (Hz)]
- Line Source Transfer Mobility (TM)
  - Describes the soil response to vibration
  - Soil
    - Alignment lie on alluvial deposits with clays, silts clays, sandy clays, and silts down to 30 m below grade and pockets of sands in between.

**SVRTP:**

- Measured TM on 9 locations
- Measurement depths varied between 15 m y 37 m
Line Source Transfer Mobility (TM)
Borehole Location

- PE Study Locations (BH or ST)
- Draft EIS/EIR Boreholes (BV)
Line Source Transfer Mobility (TM)
Building Vibration Response \((C_{building})\)

- Foundation coupling loss
- Floor resonance (amplification)
Adjustment Factors

1) Soil-Tunnel interaction
Adjustment Factors

2) Turnouts

+10 dB d<15 m
+[10-15log(d/15)] 15m <d< 50 m
+0 dB d>50 m
Vibration Criteria
## Groundborne Noise Criteria

<table>
<thead>
<tr>
<th>Land Use Category</th>
<th>Frequent Events</th>
<th>Occasional Events</th>
<th>Infrequent Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category 1</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Category 2</td>
<td>35 dBA</td>
<td>38 dBA</td>
<td>43 dBA</td>
</tr>
<tr>
<td>Category 3</td>
<td>40 dBA</td>
<td>43 dBA</td>
<td>48 dBA</td>
</tr>
<tr>
<td>Special Buildings</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concert Halls, TV Studios &amp; Rec. Studios</td>
<td>25 dBA</td>
<td>25 dBA</td>
<td></td>
</tr>
<tr>
<td>Auditoriums</td>
<td>30 dBA</td>
<td>38 dBA</td>
<td></td>
</tr>
<tr>
<td>Theaters</td>
<td>35 dBA</td>
<td></td>
<td>45 dBA</td>
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</tbody>
</table>
Analysis Results

- Groundborne vibration levels below criteria

No Vib. mitigation measures necessary
Analysis Results (cont…)

- 48 buildings (132 individual units) with potential for groundborne noise impact
Preliminary Mitigation Measures

**Highly Resilient Direct Fixation (HRDF)**

Dynamic stiffness: 14 MN/m

Dynamic/static ratio = 1.25
Preliminary Mitigation Measures

**Rail suspension fastener (RSF)**
Dynamic stiffness: approximately 8.4 MN/m
Dynamic/static ratio: 3.4

**Examples**
Delta DF and Vangard

Delta DF - ATP
Vangard - Pandrol
Preliminary Mitigation Measures

*Rail suspension fastener (RSF) (cont.)*

![Graph showing frequency distribution for different buildings.](graph.png)
Preliminary Recommendations on Vibration Mitigation

- **Highly Resilient Direct Fixation Fastener (HRDF)**
- **Rail Suspension Fastener (RSF)**
Additional Mitigation Measures Evaluated

Isolated Slab Tracks (IST)

- Similar to floating slab
- Implemented in Toronto & Sao Paulo
- Potential design: 25 to 30 cm thick slab over Sylomer or Ballast Mat
- Estimated reduction (preliminary) 10 - 14 dBA
Additional Mitigation Measures Evaluated

High Attenuation RST developed for Metro Hong Kong

- Wider block
- Thicker Pad
BART adopted resiliently supported half-tie (RST) as their design standard.

Additional study was needed to evaluate a rail support track that:
- Complies with their standard (RST), and
- Reduce groundborne noise impacts

Concrete block
- Block: 640mm x 260mm x 200 mm
- Boot: 12 mm thickness

Rubber boot
Additional Parametric Study

- **Goal:** To determine if a single track system could mitigate ALL groundborne noise impacts

- **Numerical model:**
  - Discrete rail support
  - Vehicle Model
  - Parallel impedance model
  - Tunnel invert forces
Additional Parametric Study

Track Support Systems Evaluated:

- RST Original (pad stiffness 98 MN/m, mass block 82 kg)
- RST STD (“finned boot”, pad stiffness 44 MN/m, mass block 82 kg)
- HARST (High Attenuation RST, pad stiffness 22 MN/m, mass block 109 kg)
- HARST_SP (softer pad, pad stiffness 11 MN/m, block mass 109 kg)
- HRDF (pad stiffness 14 MN/m)
Models

**Discrete Rail Support**
- Exact solutions of the Bernoulli-Euler model for discretely supported beams
- Ideal spring-mass system

**Truck Model**
- Truck represented by a 22 DOF system of wheel, axle, inertia block, motor, gear box, break and 1/2 car body
Combined Model

- Models were combined to determine force transmissibility

Force transmitted to rail head

\[ F_r(\omega) = K_r(\omega) U(\omega) = -K_r(\omega)[K_r(\omega) + K_v(\omega)]^{-1} K_v(\omega) \delta(\omega) \]

\[ F_{net}(\omega) = \sum T_r(\omega) F_r(\omega) \]

\[ |F_{TOTAL}(\omega)|^2 = |F_{net}^1(\omega)|^2 + |F_{net}^2(\omega)|^2 + |F_{net}^3(\omega)|^2 + |F_{net}^4(\omega)|^2 \]
Model Schematic

Complete

Simplified
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>ORIG RST</th>
<th>STD RST</th>
<th>HA_RST</th>
<th>HA_RST_SP</th>
<th>HRDF</th>
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<tbody>
<tr>
<td>Main Pad Vertical Stiffness</td>
<td>MN/m</td>
<td>98.0</td>
<td>44.0</td>
<td>22.0</td>
<td>11.0</td>
<td>14.0</td>
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<td>Main Pad Rotational Stiffness</td>
<td>MN-m</td>
<td>2.22</td>
<td>1.00</td>
<td>0.5</td>
<td>0.25</td>
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<td>Rail Pad Vertical Stiffness</td>
<td>MN/m</td>
<td>178</td>
<td>178</td>
<td>178</td>
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<tr>
<td>Isolation Mass Top Plate</td>
<td>Kg</td>
<td>82.0</td>
<td>82.0</td>
<td>109</td>
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<tr>
<td>Isolation Rotational Inertia</td>
<td>Kg-m²</td>
<td>0.82</td>
<td>0.82</td>
<td>2.45</td>
<td>2.45</td>
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<tr>
<td>Block Resonance</td>
<td>Hz</td>
<td>291</td>
<td>261</td>
<td>215</td>
<td>209</td>
<td>N/A</td>
</tr>
<tr>
<td>Rail+Block Resonance</td>
<td>Hz</td>
<td>139</td>
<td>93</td>
<td>60</td>
<td>42</td>
<td>84</td>
</tr>
</tbody>
</table>
Expected Reduction Levels

- Results of the simplified model (re: ORIG_RST)
Conclusions

- A combination of highly resilient direct fixation fastener and rail suspension fasteners could be a viable solution to eliminate groundborne noise impacts.

- The parametric analysis indicates that high attenuation resiliently supported track with softer boot and pad HARST_SP could be a uniform solution for the project. However, before adoption by the Project, results will be validated with field measurements.
Acknowledge

- Bay Area Rapid Transit (BART)
- HMM/Bechtel