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

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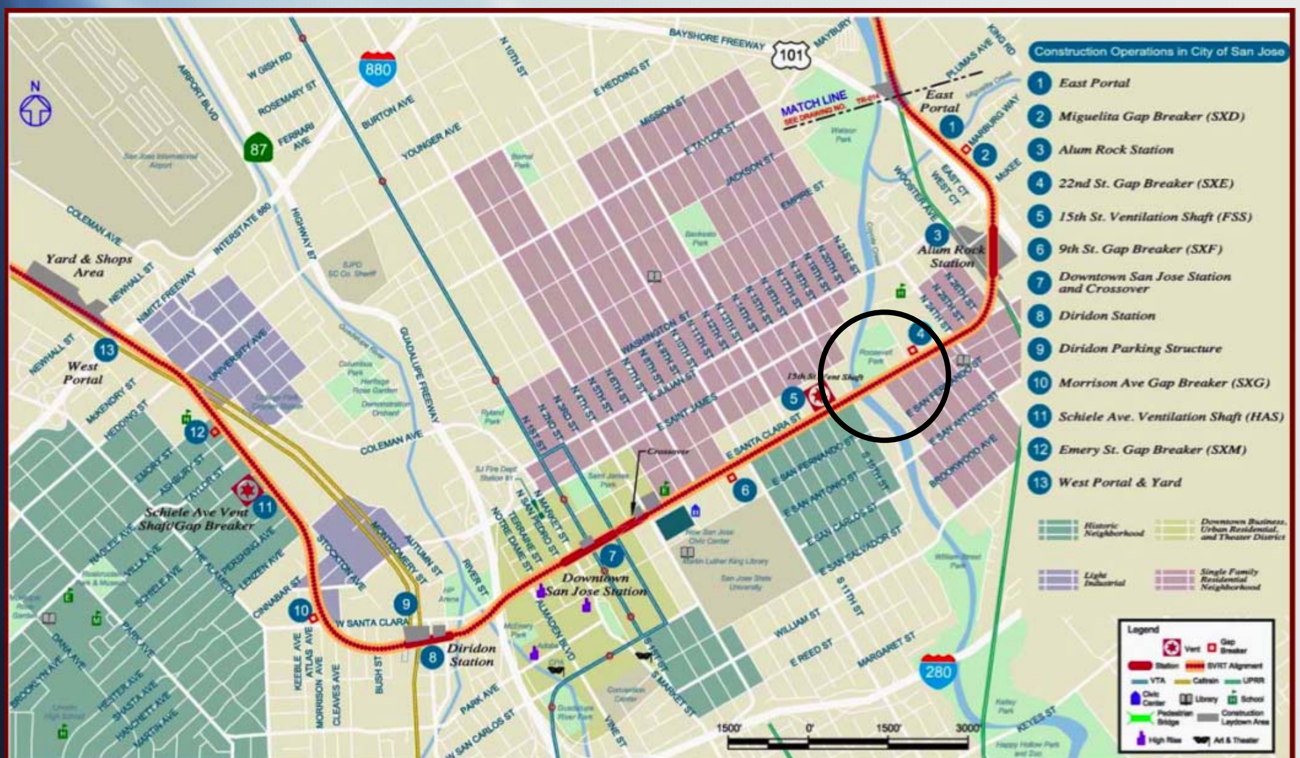
Outline

- 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)

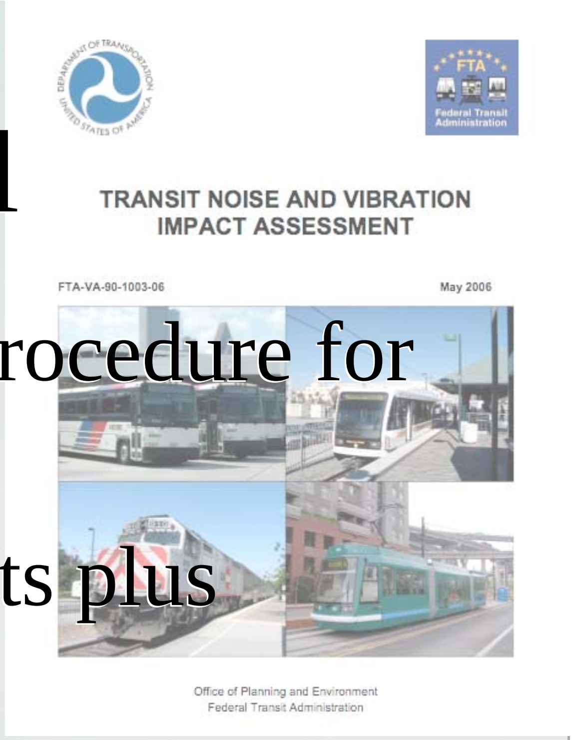
- 8.6 Km underground
  - Double bored tunnel (6,900 m)
  - Cut and cover (at 3 stations - 990 m)
- Design speed: 72 Km/h and 105 Km/h
- Base alignment + 2 options at Coyote Creek



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

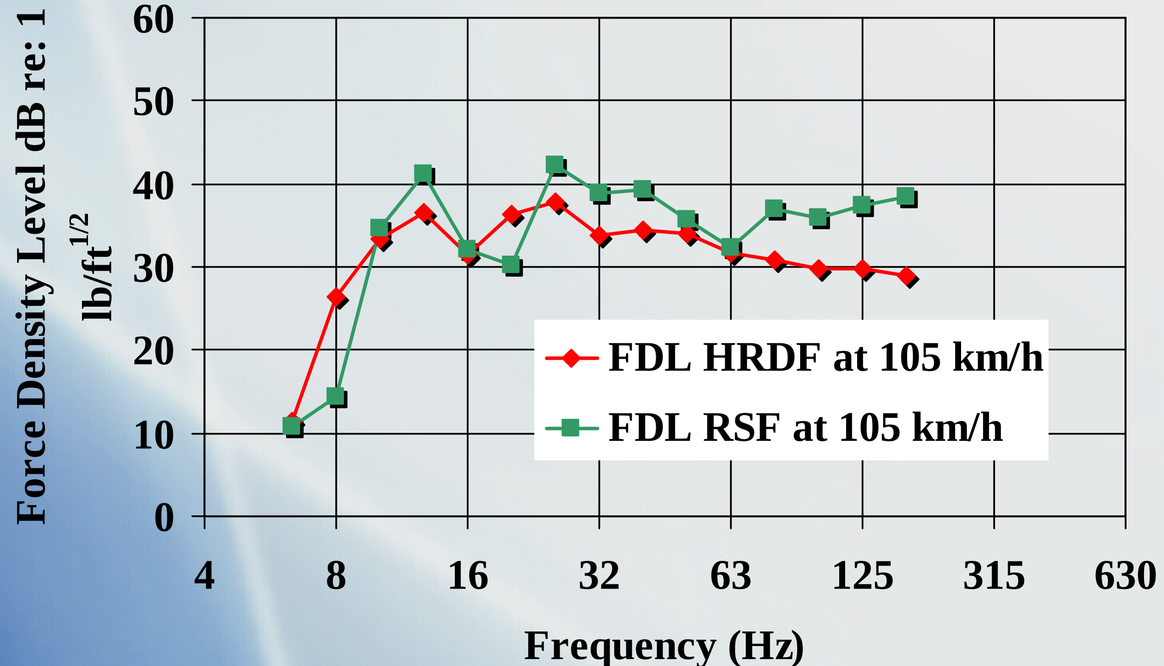
$$L_v = L_{fd} + TM_{lineal} + C_{building} + \text{Adjust.} + \text{Design Factor}$$

- Groundborne noise

$$L_A = L_v + K_{rad} + K_{A\text{-}wt}$$

▪ Force Density Level (L_{fd})

- ✓ Characteristic of the system (vehicle)
- ✓ Track type (ballast, direct fixation track, etc)
- ✓ Speed

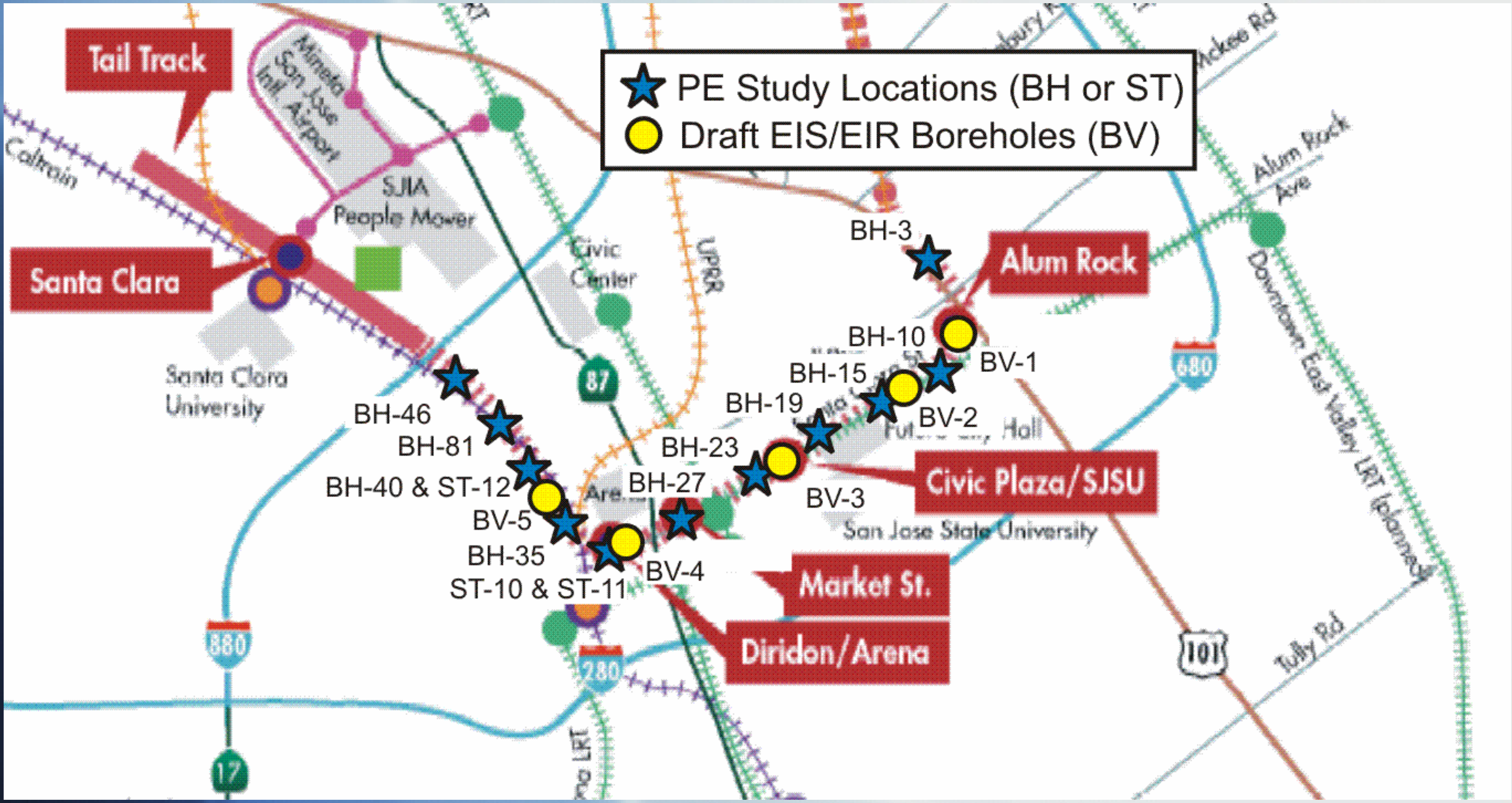


- Line Source Transfer Mobility (*TM*)
  - Describes the soil response to vibration
  - Soil
    - Alignment lie on alluvial deposits with clays, silts clays, sandy clays, and silts down to 30 m below grade and pockets of sands in between.

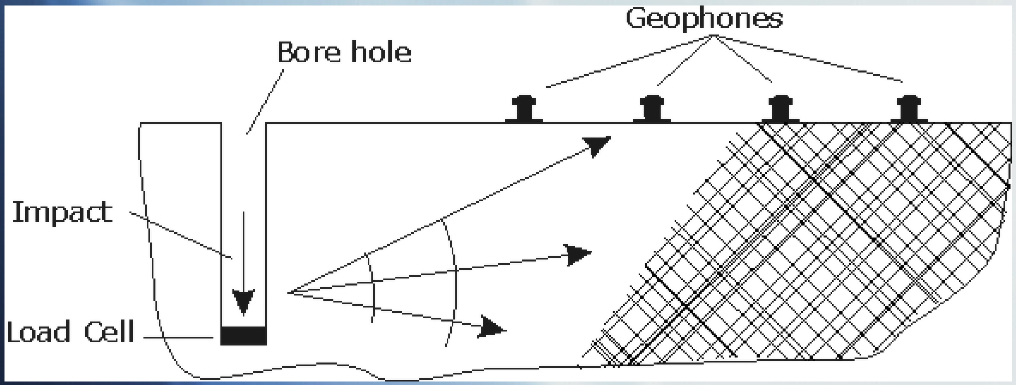
SVRTP:

- Measured TM on 9 locations
- Measurement depths varied between 15 m y 37 m

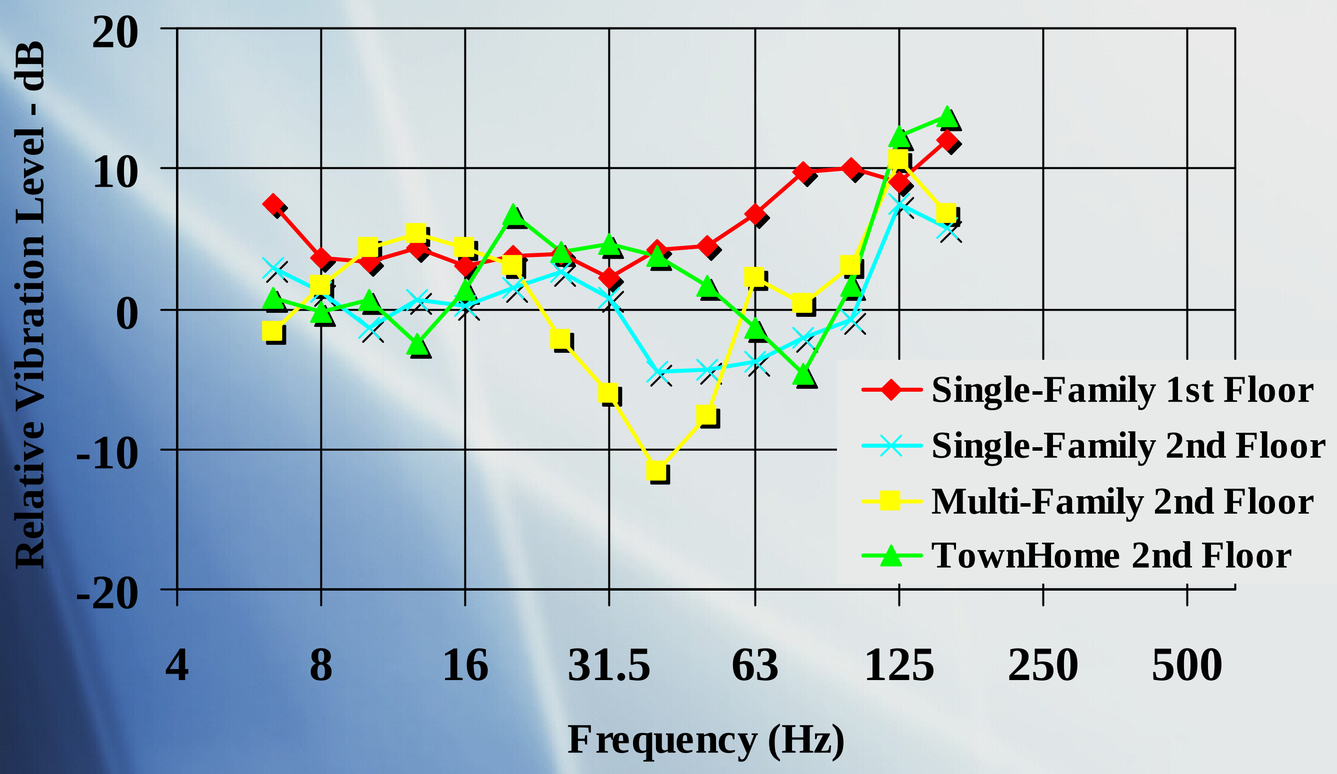
Line Source Transfer Mobility (*TM*) Borehole Location



- Line Source Transfer Mobility (*TM*)

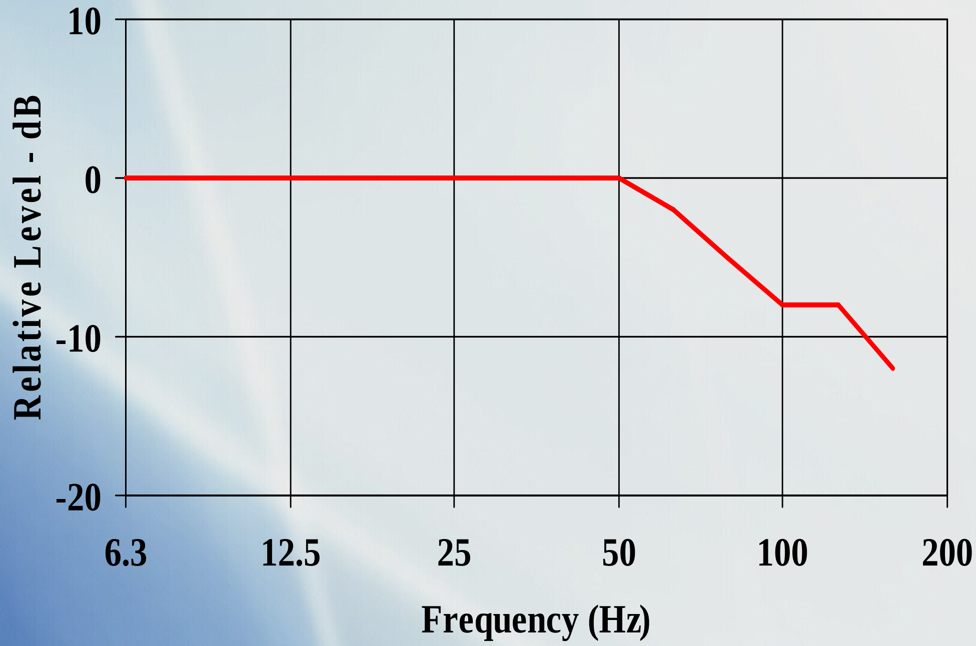


- Building Vibration Response ($C_{building}$)
  - Foundation coupling loss
  - Floor resonance (amplification)



- # Adjustment Factors

1) Soil-Tunnel interaction



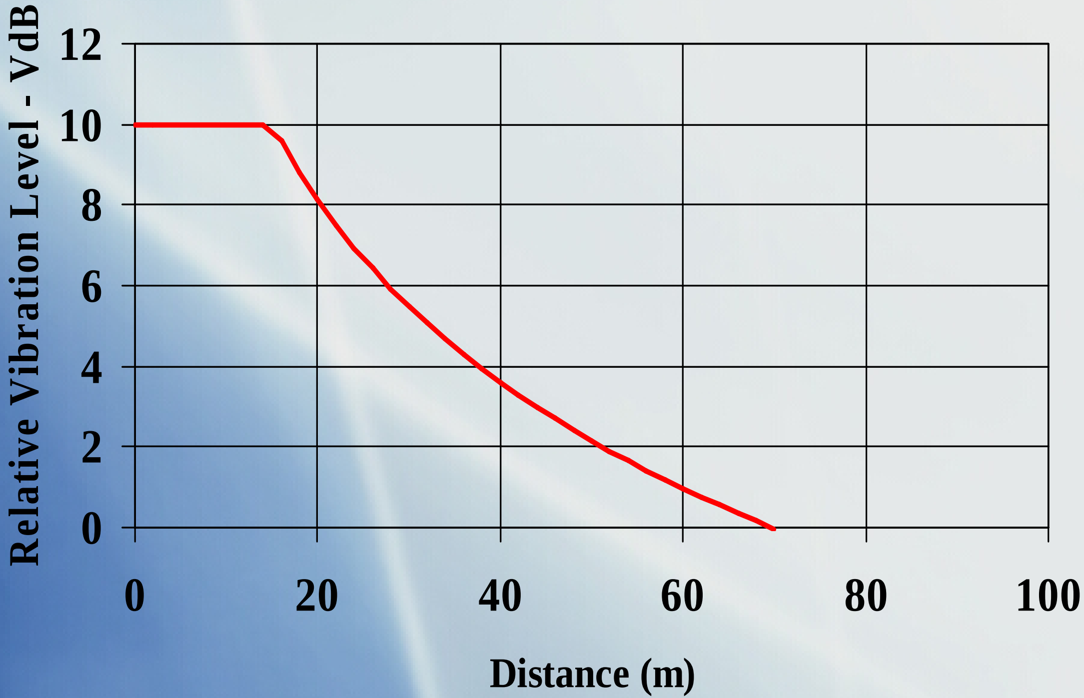
- # Adjustment Factors

2) Turnouts

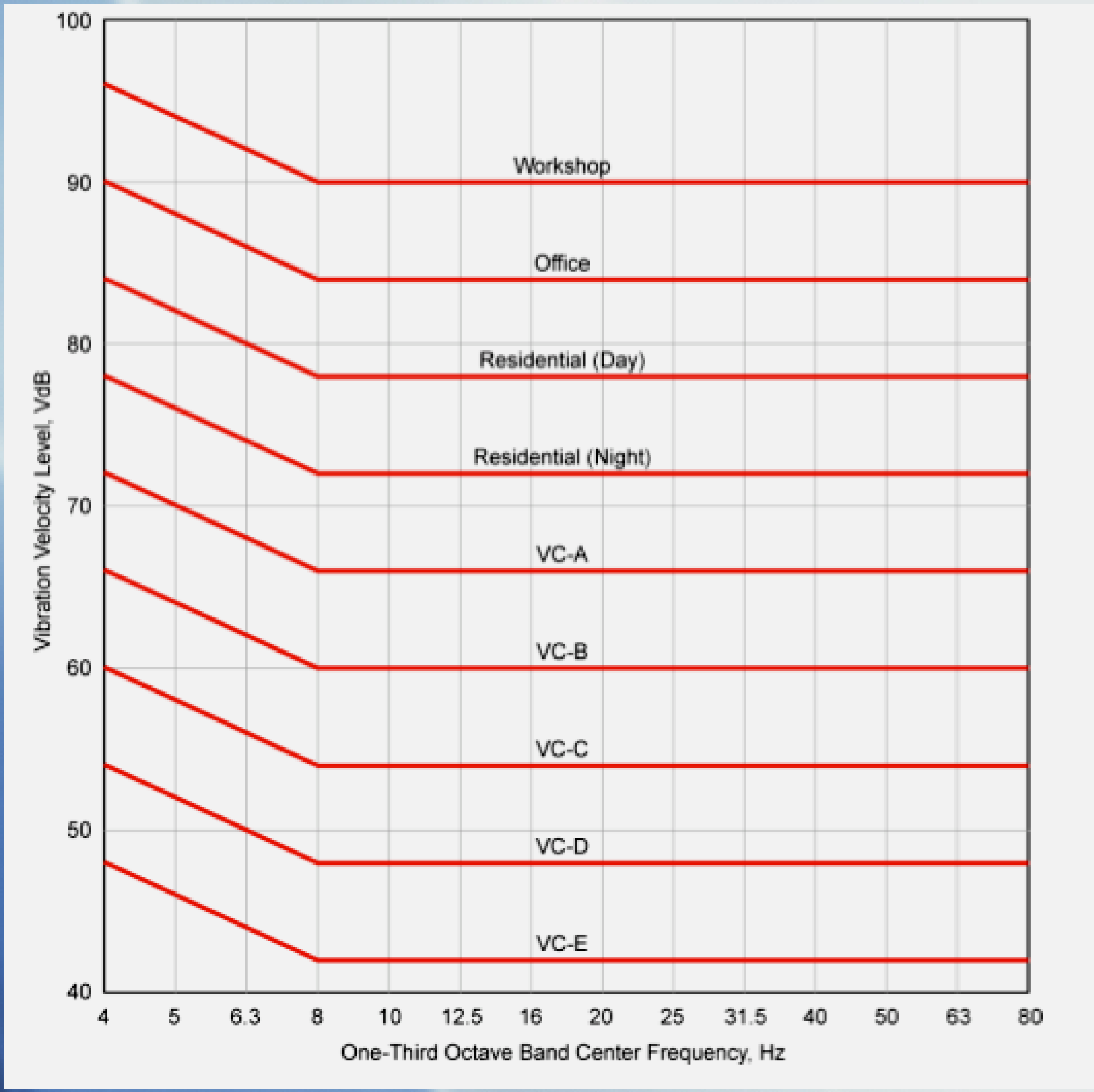
+10 dB d<15 m

+[10-15log(d/15)] 15m <d< 50 m

+0 dB d>50 m



Vibration Criteria

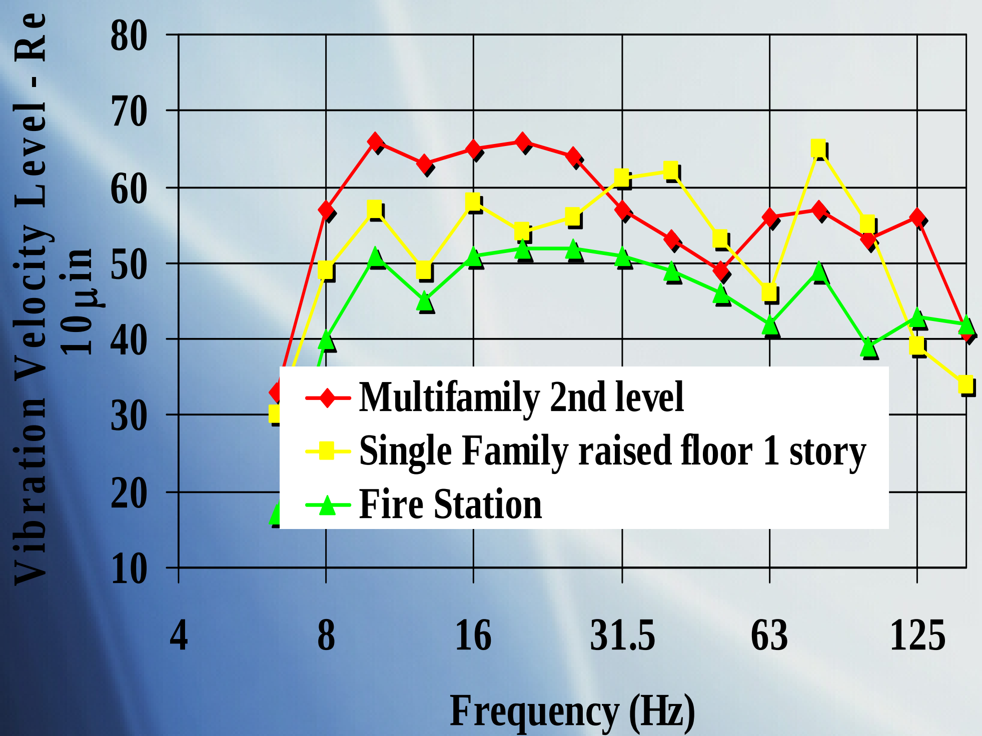


Groundborne Noise Criteria

Land Use Category	Frequent Events	Occasional Events	Infrequent Events
Category1	N/A	N/A	N/A
Category 2	35 dBA	38 dBA	43 dBA
Category 3	40 dBA	43 dBA	48 dBA
Special Buildings			
Concert Halls, TV Studios & Rec. Studios	25 dBA	25 dBA	
Auditoriums	30 dBA	38 dBA	
Theaters	35 dBA	45 dBA	

Analysis Results

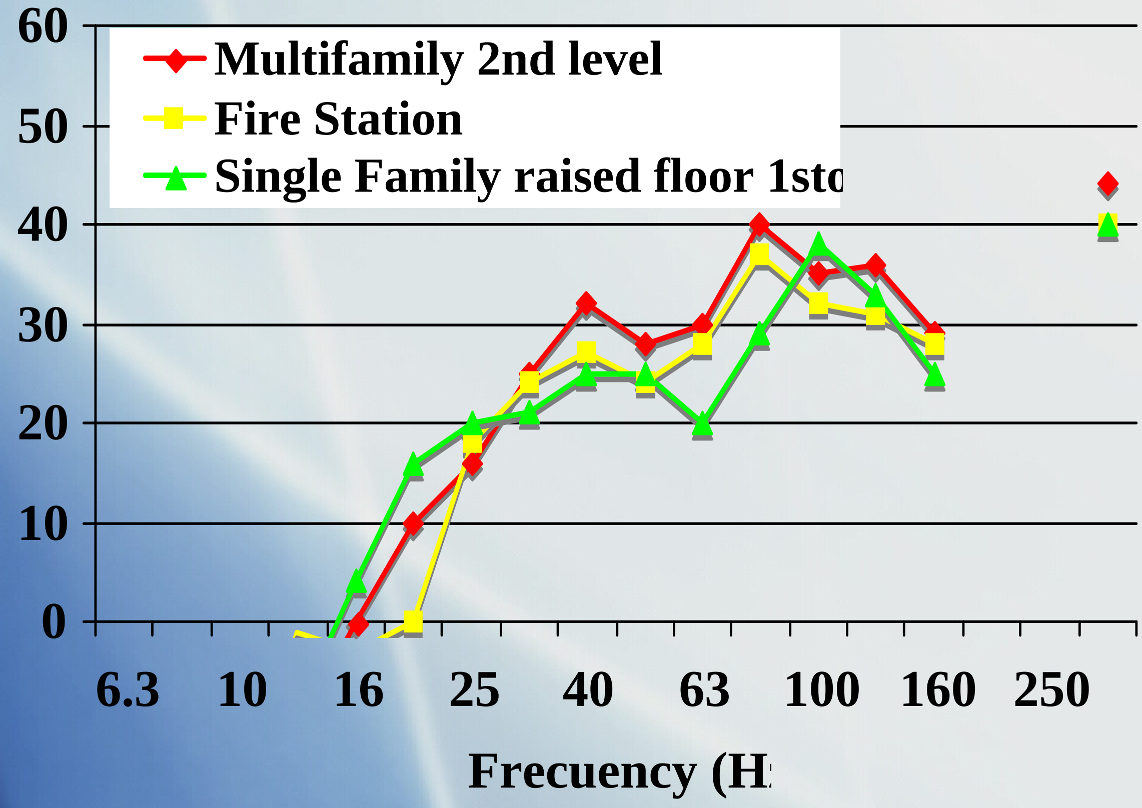
- Groundborne vibration levels below criteria



No Vib. mitigation measures necessary

Analysis Results (cont…)

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

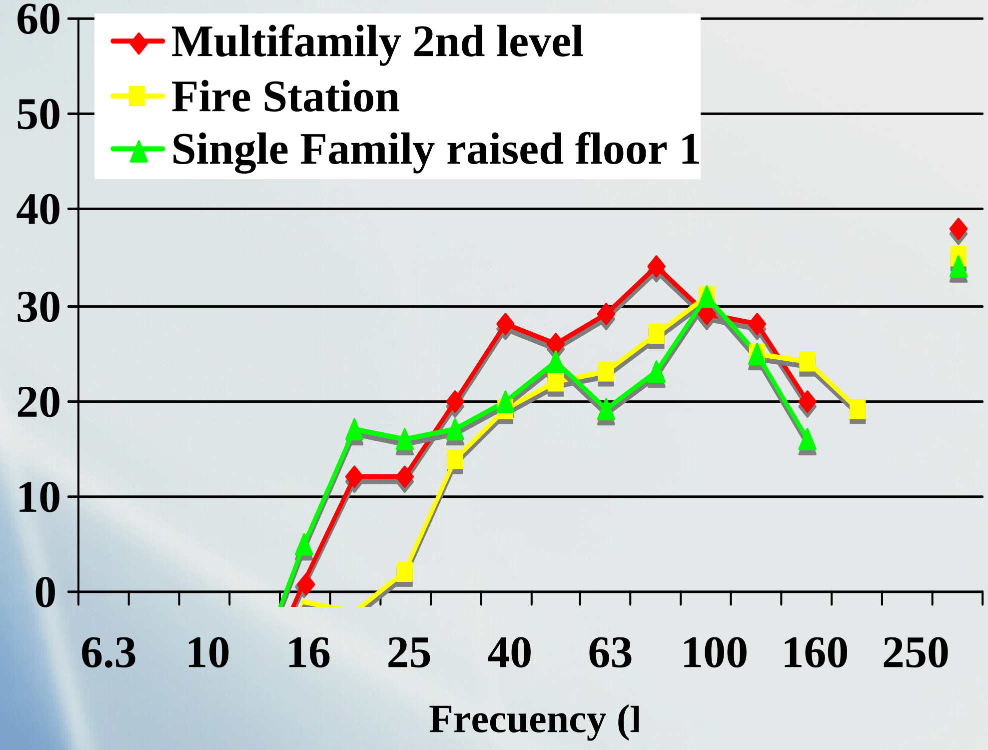


Preliminary Mitigation Measures

Highly Resilient Direct Fixation (HRDF)

Dynamic stiffness: 14 MN/m

Dynamic/static ratio = 1.25



Preliminary Mitigation Measures

Delta DF - ATP

Rail suspension fastener (RSF)

Dynamic stiffness: approximately 8.4 MN/m

Dynamic/static ratio: 3.4

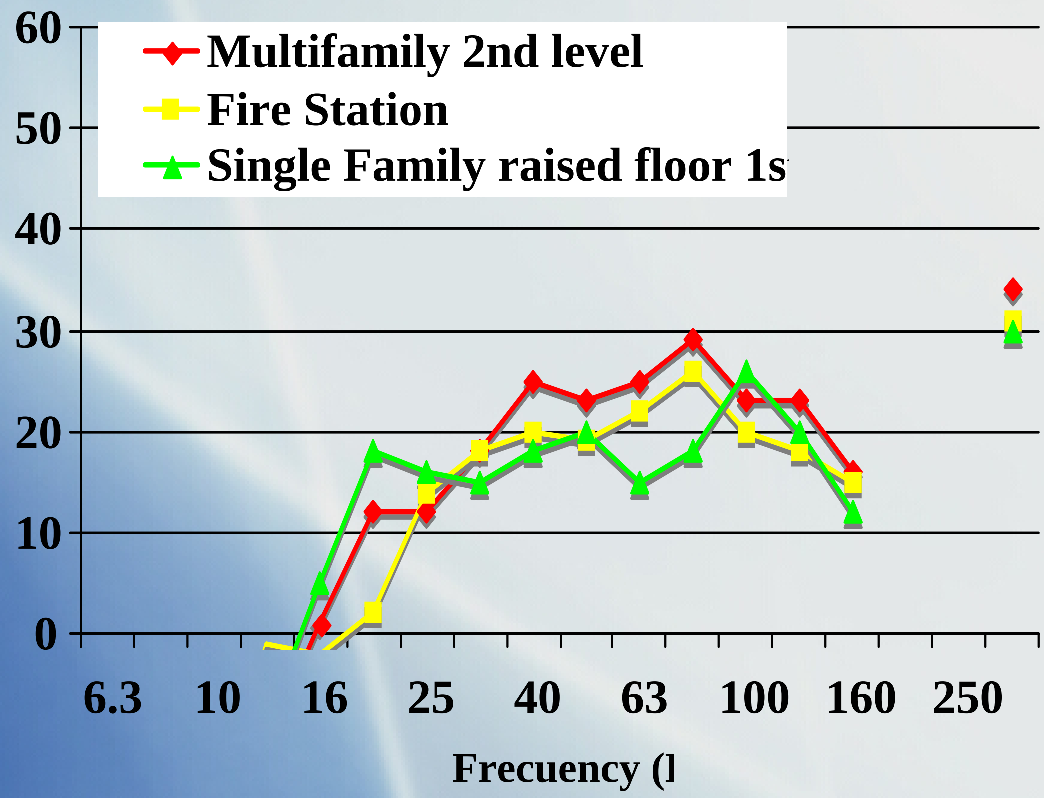
<u>Examples</u>

Delta DF and Vangard

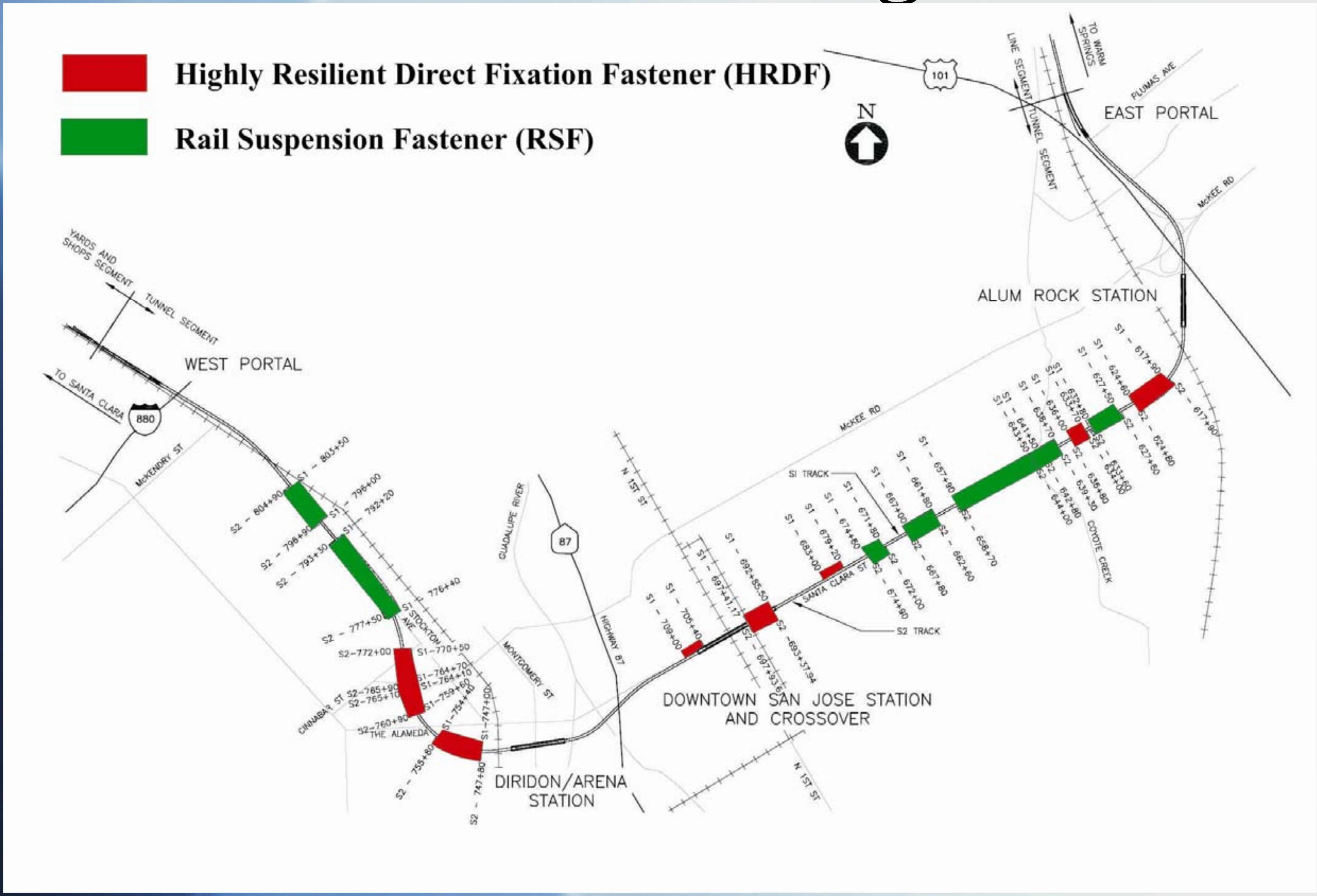
Vangard - Pandrol

Preliminary Mitigation Measures

Rail suspension fastener (RSF)(cont.)



Preliminary Recommendations on Vibration Mitigation

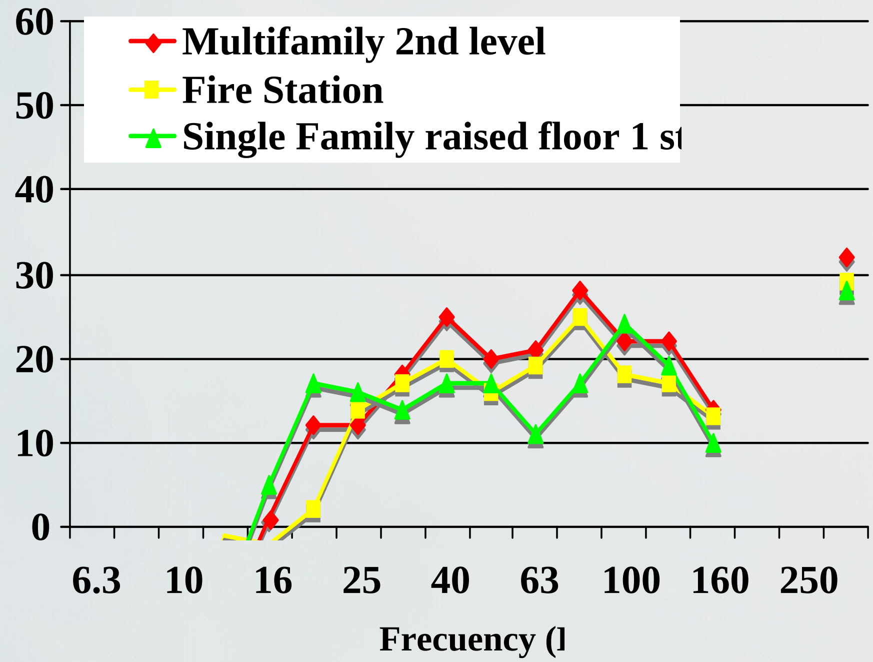


Additional Mitigation Measures Evaluated

Isolated Slab Tracks (IST)

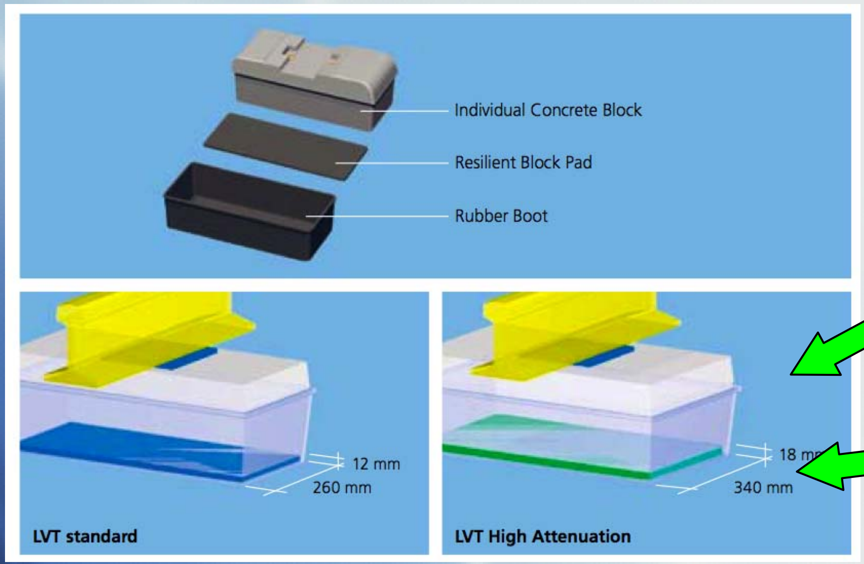
- Similar to floating slab
- Implemented in Toronto & Sao Paulo
- Potential design:

  25 to 30 cm thick slab over Sylomer or Ballast Mat
- Estimated reduction (preliminary) 10 - 14 dBA



Additional Mitigation Measures Evaluated

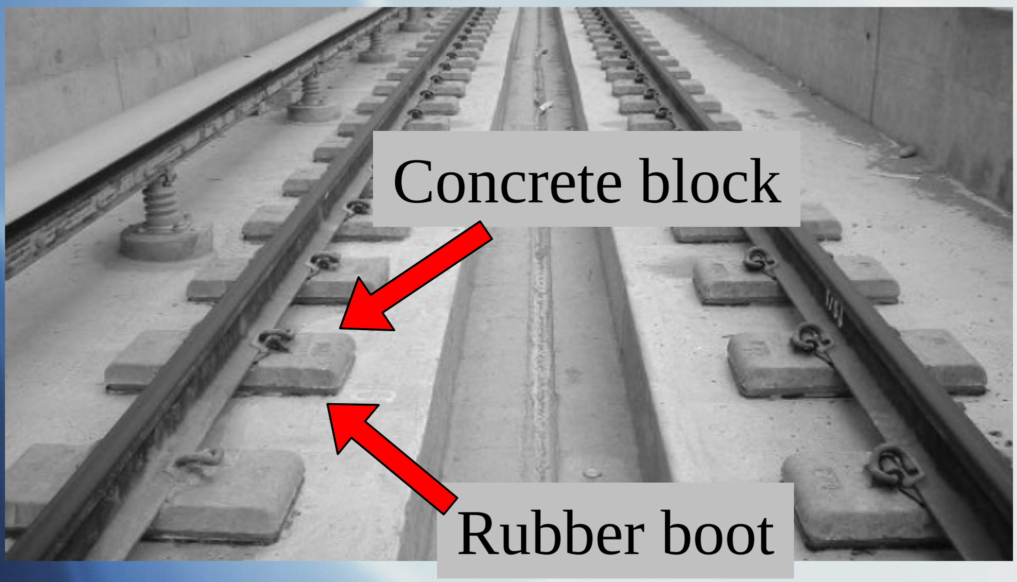
High Attenuation RST developed for Metro Hong Kong



Wider block

Thicker Pad

- BART adopted resiliently supported half-tie (RST) as their design standard



Block:
640mm x 260mm x 200 mm
Boot
12 mm thickness

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

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

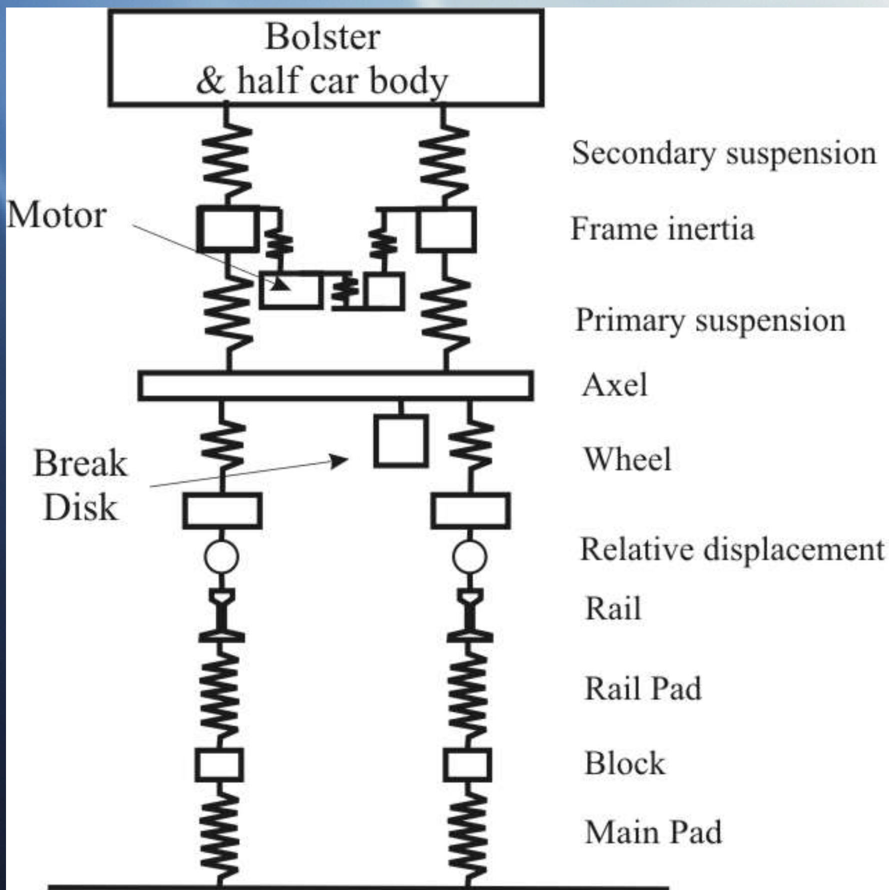
Force transmitted to rail head

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

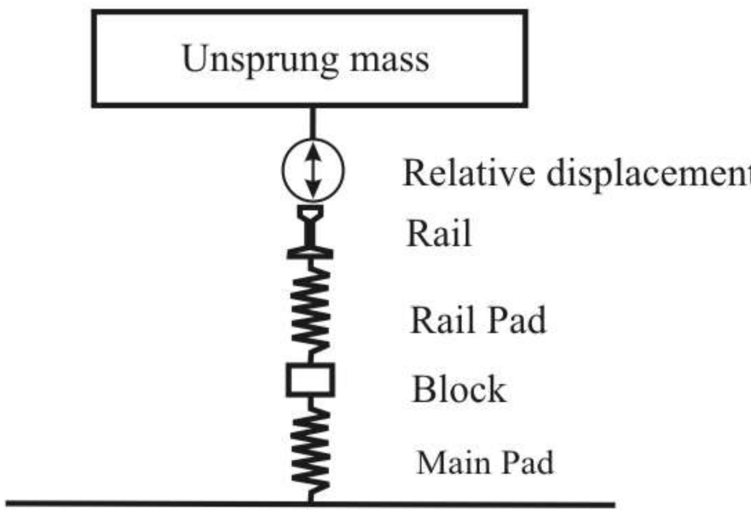
$$F_{net}(\omega) = \sum T_r(\omega)F_r(\omega)$$

$$|F_{TOTAL}(\omega)|^2 = |F^1{}_{net}(\omega)|^2 + |F^2{}_{net}(\omega)|^2 + |F^3{}_{net}(\omega)|^2 + |F^4{}_{net}(\omega)|^2$$

Model Schematic



Complete



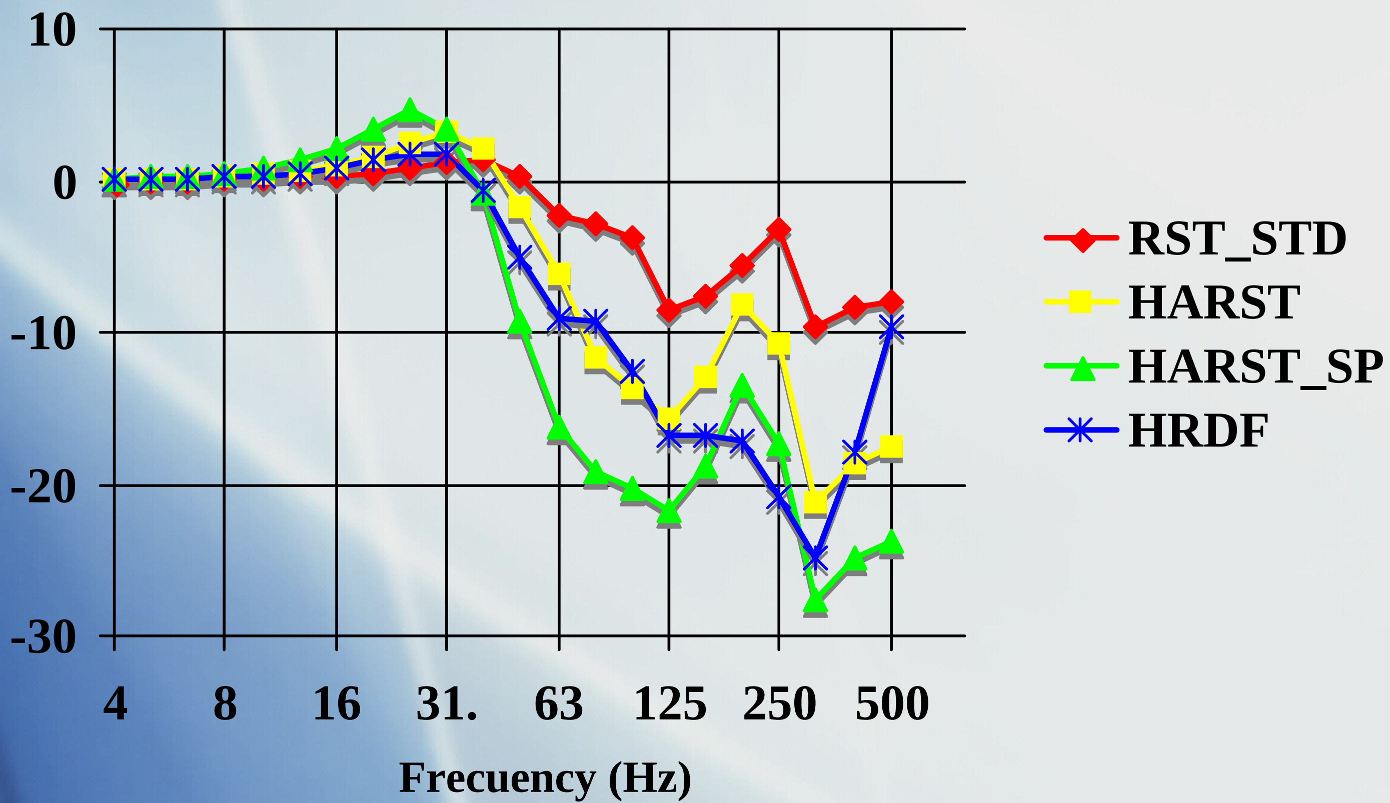
Simplified

Track Parameters

Parameter	**Unit**	**ORIG RST**	**STD RST**	**HA_ RST**	**HA_RST_ SP**	**HRDF**
Main Pad Vertical Stiffness	MN/m	98.0	44.0	22.0	11.0	14.0
Main Pad Rotational Stiffness	MN-m	2.22	1.00	0.5	0.25	0.0365
Rail Pad Vertical Stiffness	MN/m	178	178	178	178	N/A
Isolation Mass Top Plate	Kg	82.0	82.0	109	109	N/A
Isolation Rotational Inertia	$Kg\text{-}m^2$	0.82	0.82	2.45	2.45	N/A
Block Resonance	Hz	291	261	215	209	N/A
Rail+Block Resonance	Hz	139	93	60	42	84

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