

Evaluation of the Ground-Borne Vibration Reduction Properties of Tire Derived Aggregate (TDA) on the Denver RTD Light Rail System

**10th International Workshop on Railway Noise
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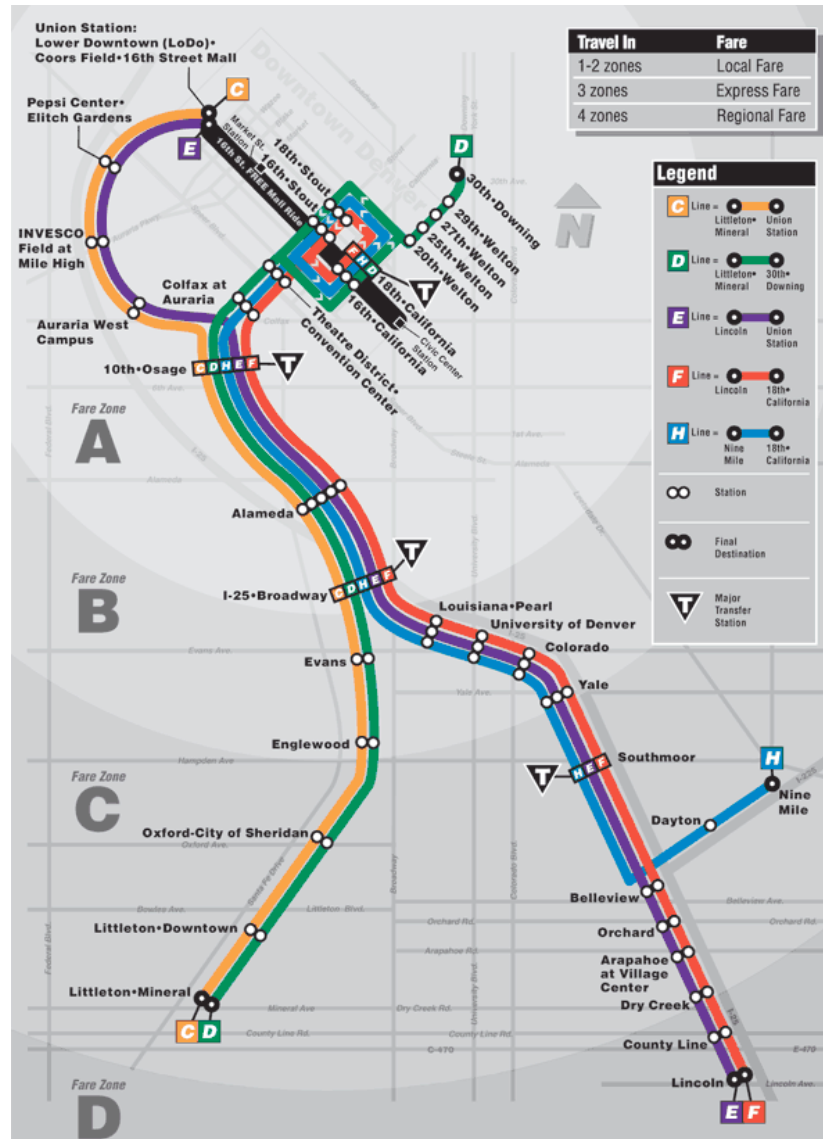
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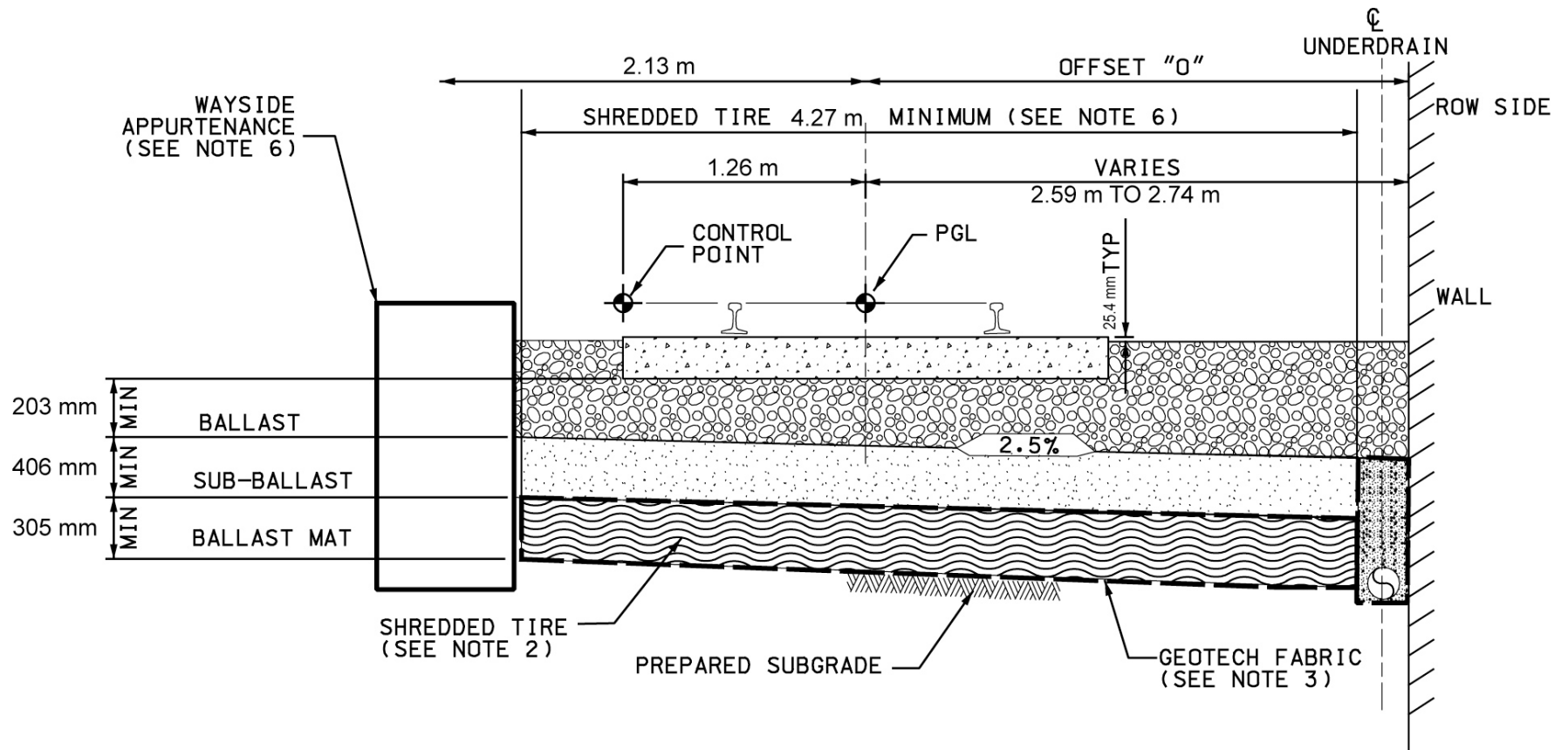
Map of the Denver RTD Light Rail System

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Cross Section of TDA (Shredded Tire) Underlayment

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TDA Installation on the Southeast (T-REX) Corridor

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Typical T-REX Corridor Track Alignment Configuration

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Summary of TDA Vibration Test Methodology

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- **Tests conducted at five T-REX sites on Nov. 9-12, 2009**
 - Four TDA sites and one control site (w/standard ballast & tie)
 - All sites located on southbound side of tracks and sound wall
- **LRT ground vibration tests at 3 positions and 3 speeds**
 - Distances of 4.5, 9 & 13.5 m from SB track (9, 13.5 & 18 m re NB)
 - Typ. 2 runs in ea. direction on ea. track at 40, 64 and 88 km/h
- **LRT tests conducted with a dedicated 2-car train set**
 - Newer Siemens Model SD160 light rail vehicles (#269 & #270)
 - Vehicles were empty with weight of about 40,600 kg each (AW-0)
- **Vibration propagation tests also conducted at each site**
 - Ground impact force generated at 11 points along a 46 m-long line
 - Ground vibration response measured at 4.5, 9, 13.5 and 18 m

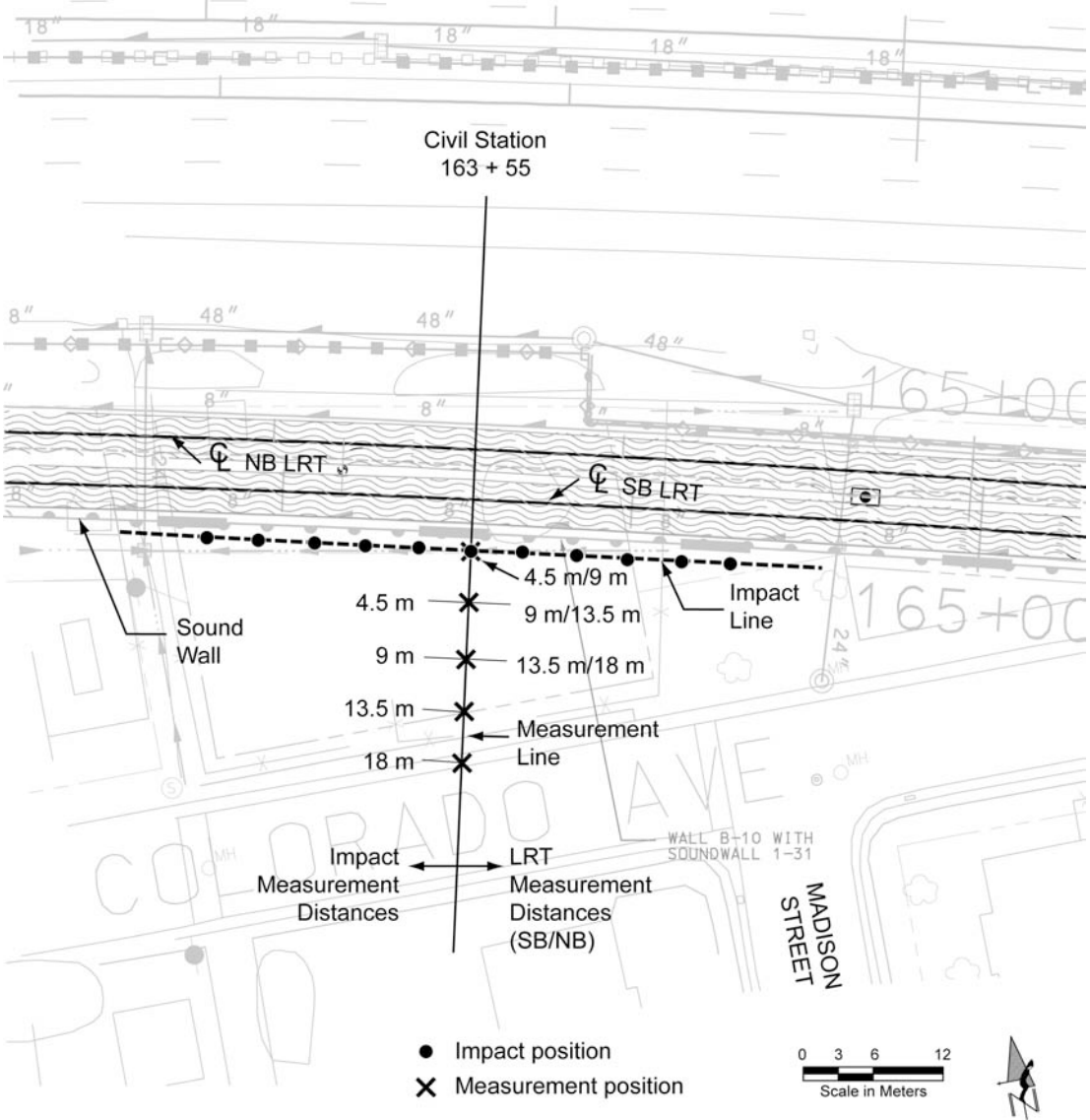
Vibration Test Site Locations

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| SITE | CIVIL STATION | DESCRIPTION |
|----------------|----------------------|---|
| Control | 140+00 | Public street area in the vicinity of Clayton Street and Colorado Avenue (Denver) |
| TDA-1 | 163+55 | Public park area in the vicinity of Colorado Avenue and Madison Street (Denver) |
| TDA-5 | 221+15 | Public street area in the vicinity of S Eudora Street and S Dahlia Street (Denver) |
| TDA-8 | 363+50 | Canyon Club Condominium grounds, in parking area near north end of complex |
| TDA-9 | 371+75 | Canyon Club Condominium grounds, in parking area near south end of complex |

Vibration Measurement Configuration at Site TDA-1

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View of Vibration Test Set-up at Site TDA-1

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Denver RTD Siemens SD160 Light Rail Test Vehicle #270

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Vibration Test Instrumentation

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- **Sensors**
 - PCB Model 393A and 393C Accelerometers
 - Honeywell Sensotec Load Cell
- **Signal Conditioning Equipment**
 - PCB 480C02 Power Supplies
 - EPAC Amplifiers
- **Recording Equipment**
 - TEAC Model LX-110 Digital Recording Unit
 - TEAC Model RD-145T Digital Audio Tape Recorder
- **Vibration Calibration Reference**
 - PCB 492B Transducer Simulator

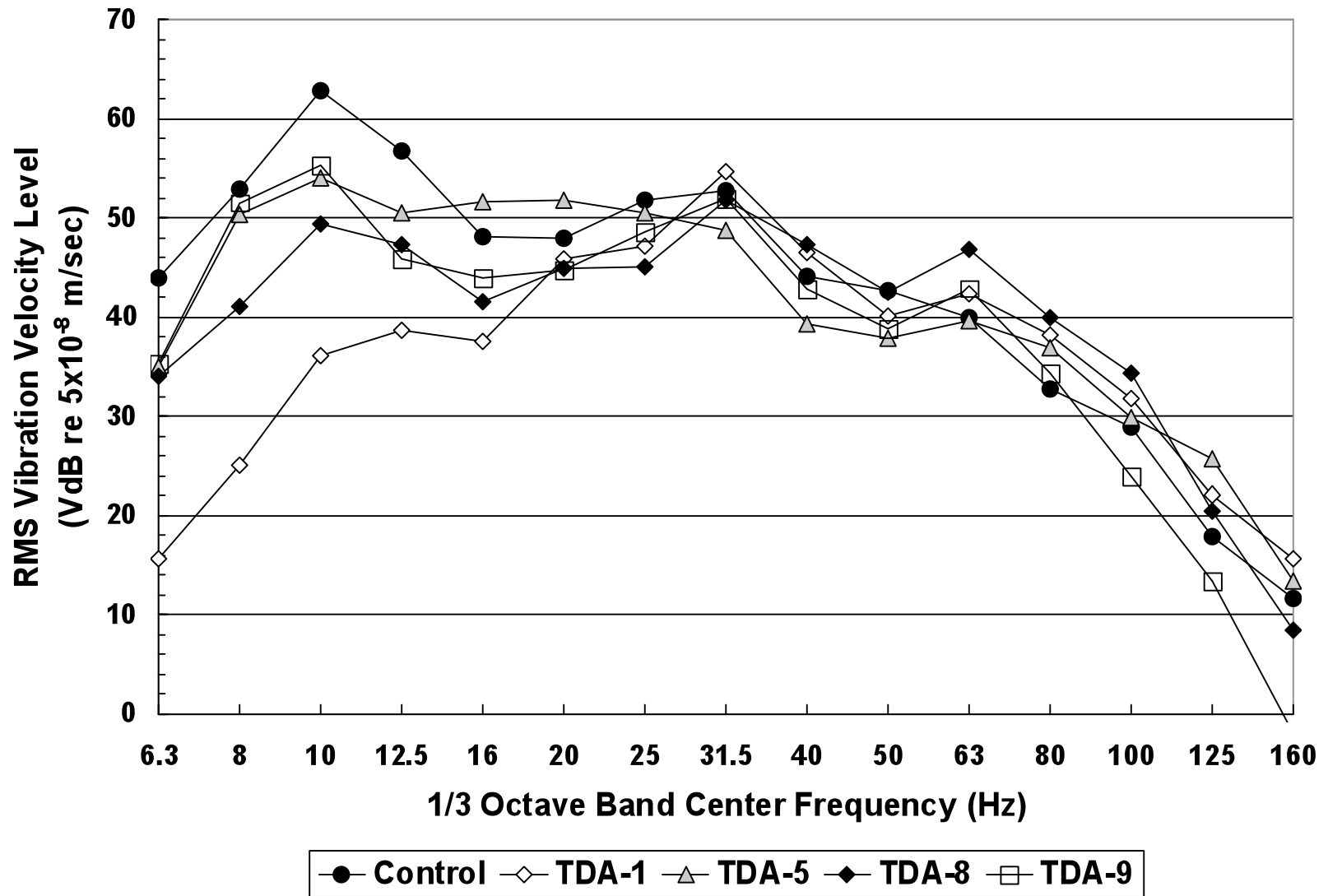
Vibration Data Analysis

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- **LRT Vibration Data Analysis**
 - Acceleration signals converted to velocity levels (L_v) in one-third octave bands using digital signal processing software
 - Train events characterized by computing the energy-average vibration level over the duration between the “3-dB down points” (with respect to the overall maximum vibration level)
- **Vibration Propagation Data Analysis**
 - Data processed into point source transfer mobilities (PSTM)
 - PSTM integrated into line source transfer mobilities (LSTM)
- **Force Density Level Calculation: $FDL = L_v - LSTM$**
 - FDL describes force that excites the ground - includes vehicle and track structure effects but excludes local geology effects
 - TDA effectiveness evaluated by comparing FDL at TDA sites with FDL at the control site

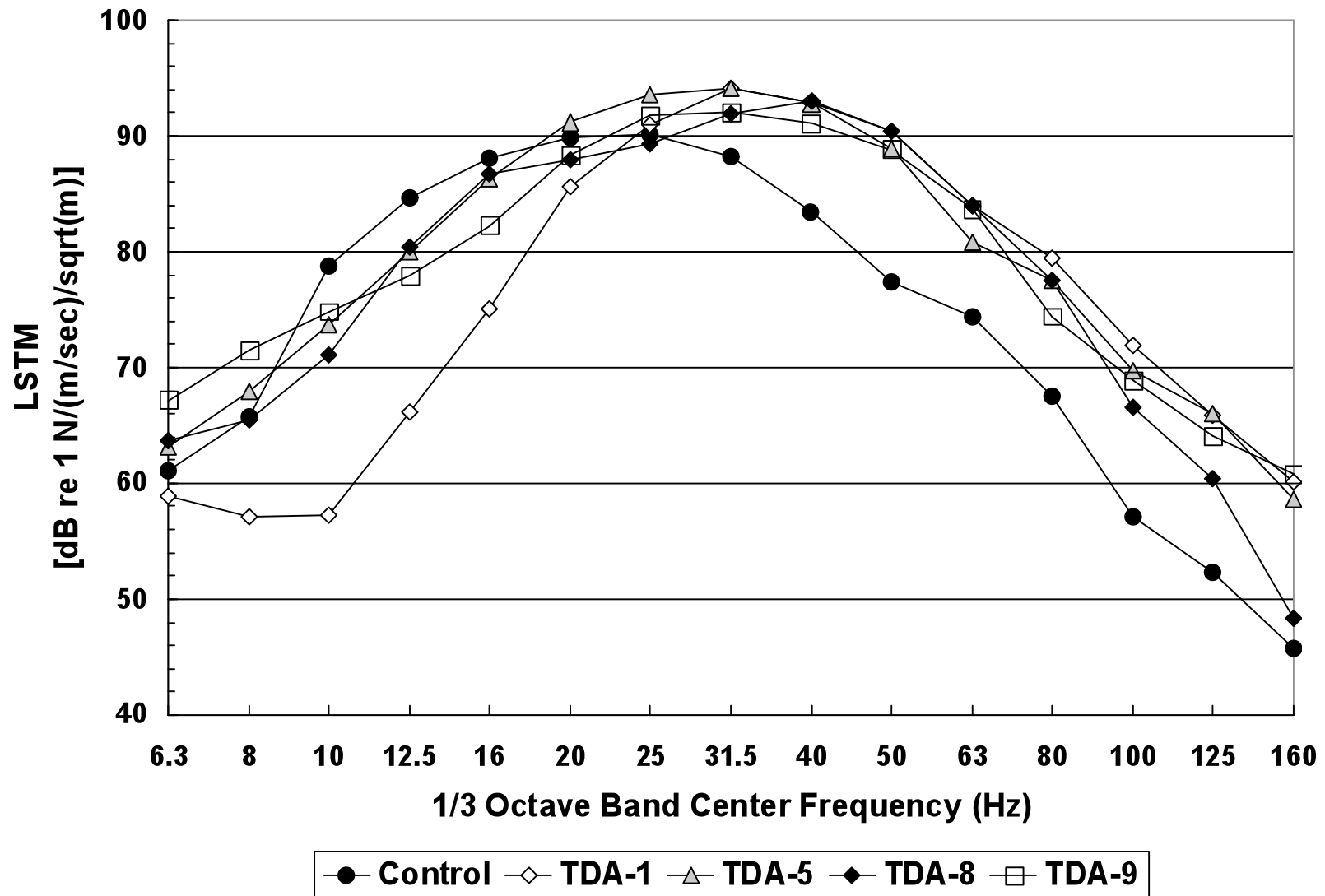
Average Measured LRT Vibration Levels (9m, 88 km/h)

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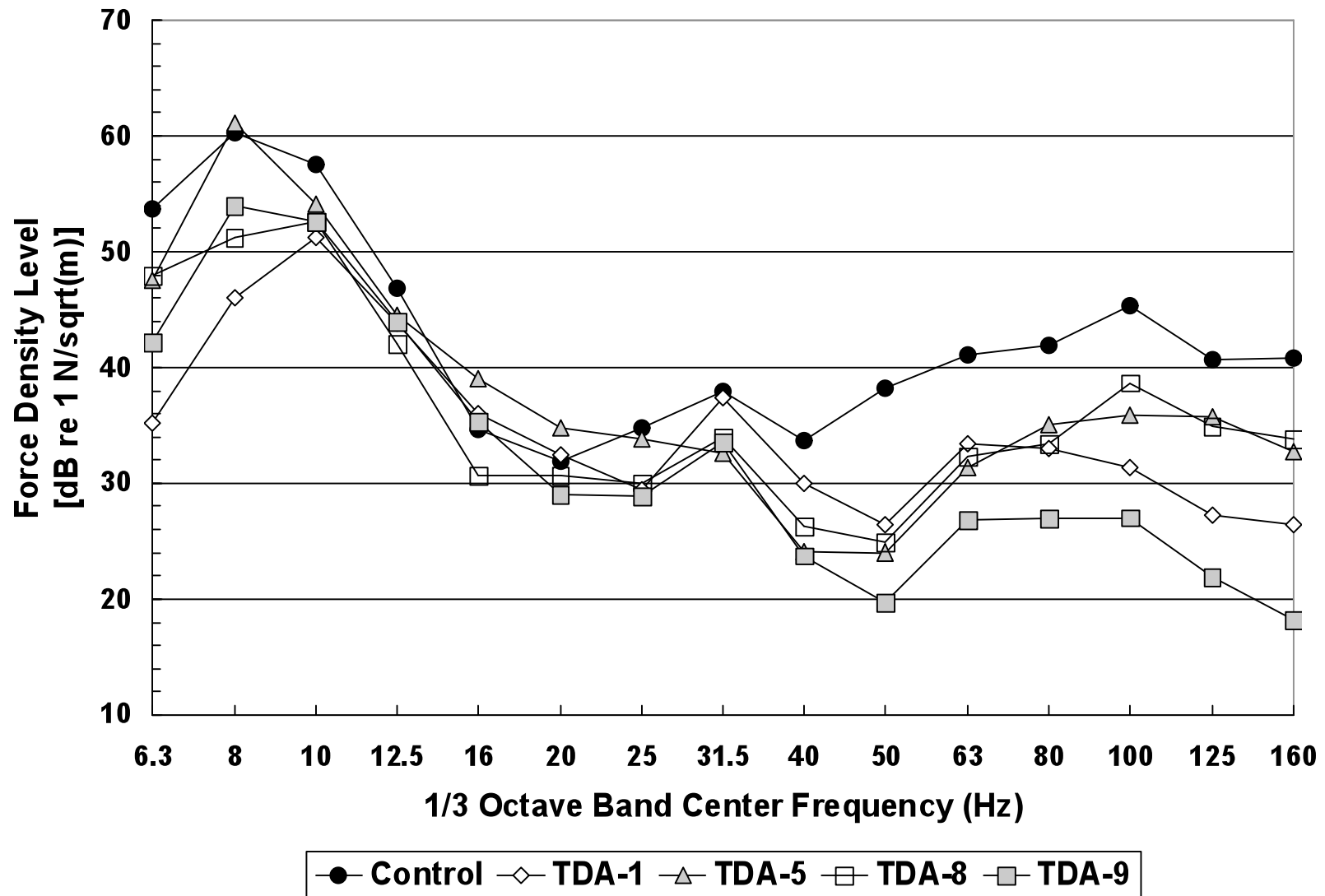
Line Source Response (LSTM) Results at 9 Meters

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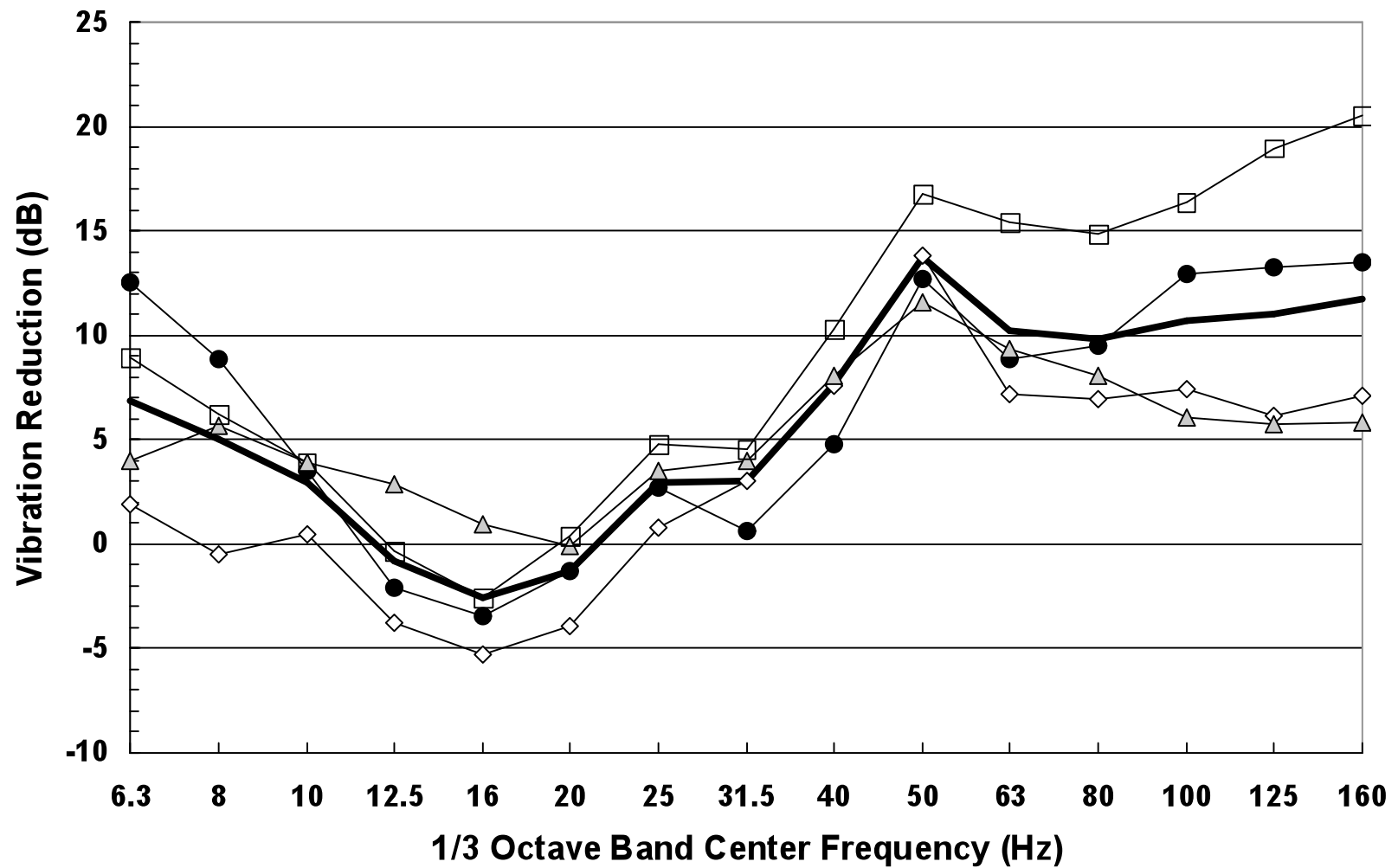
Force Density Levels at 88 km/h

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Average TDA Vibration Reduction at Denver RTD

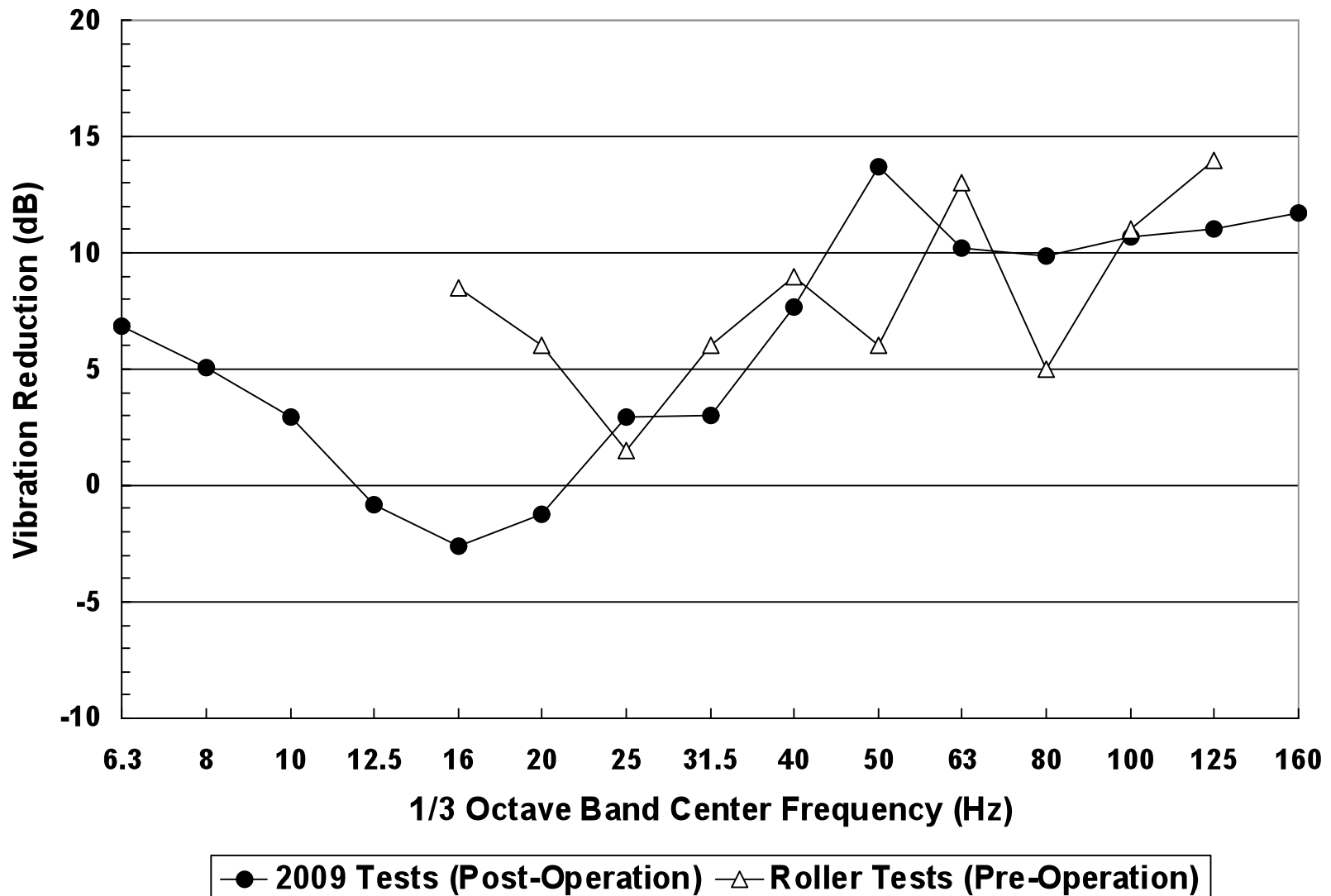
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● TDA-1 ◇ TDA-5 △ TDA-8 □ TDA-9 — AVERAGE

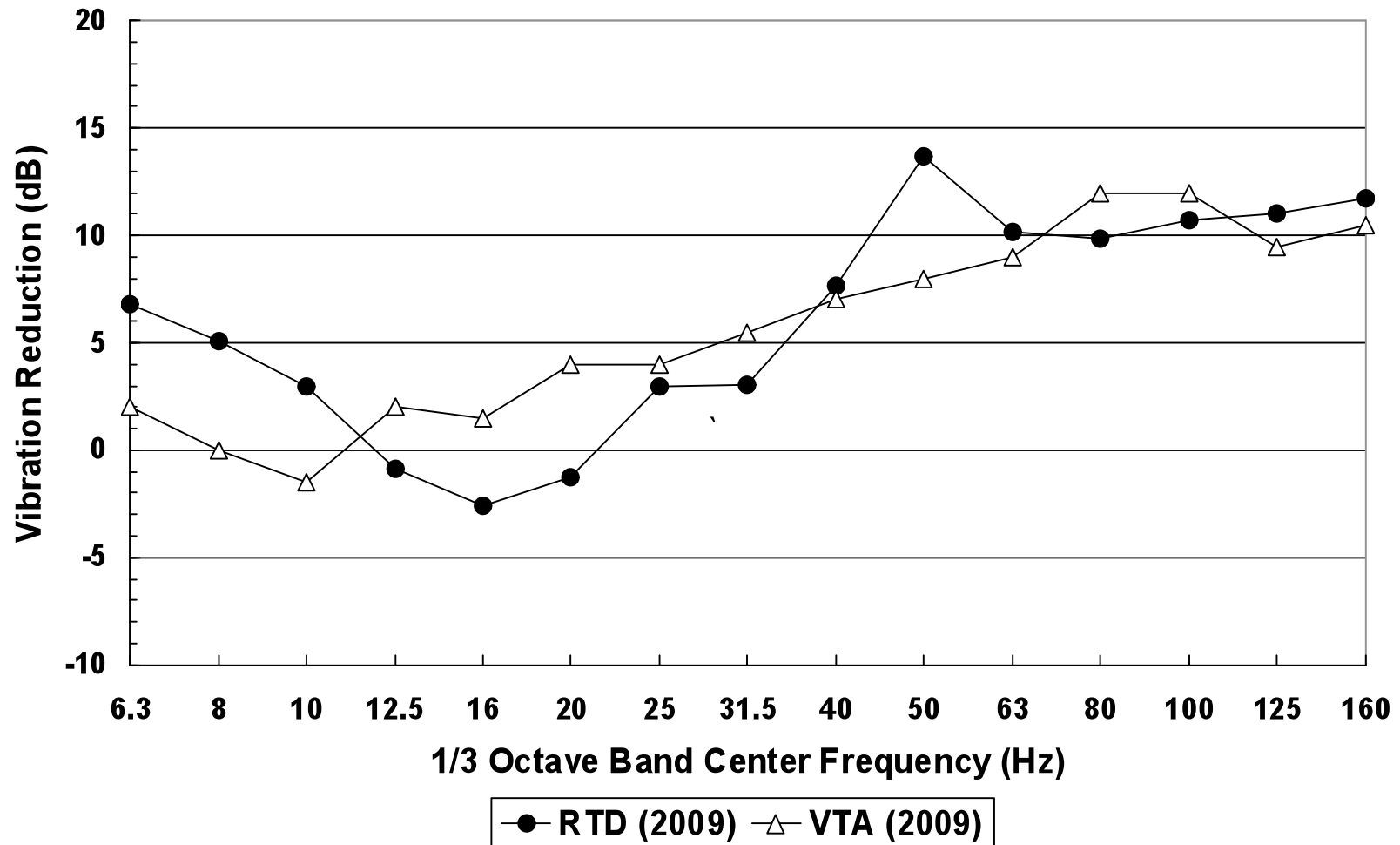
Comparison of Pre- and Post-Operation Tests at Denver RTD

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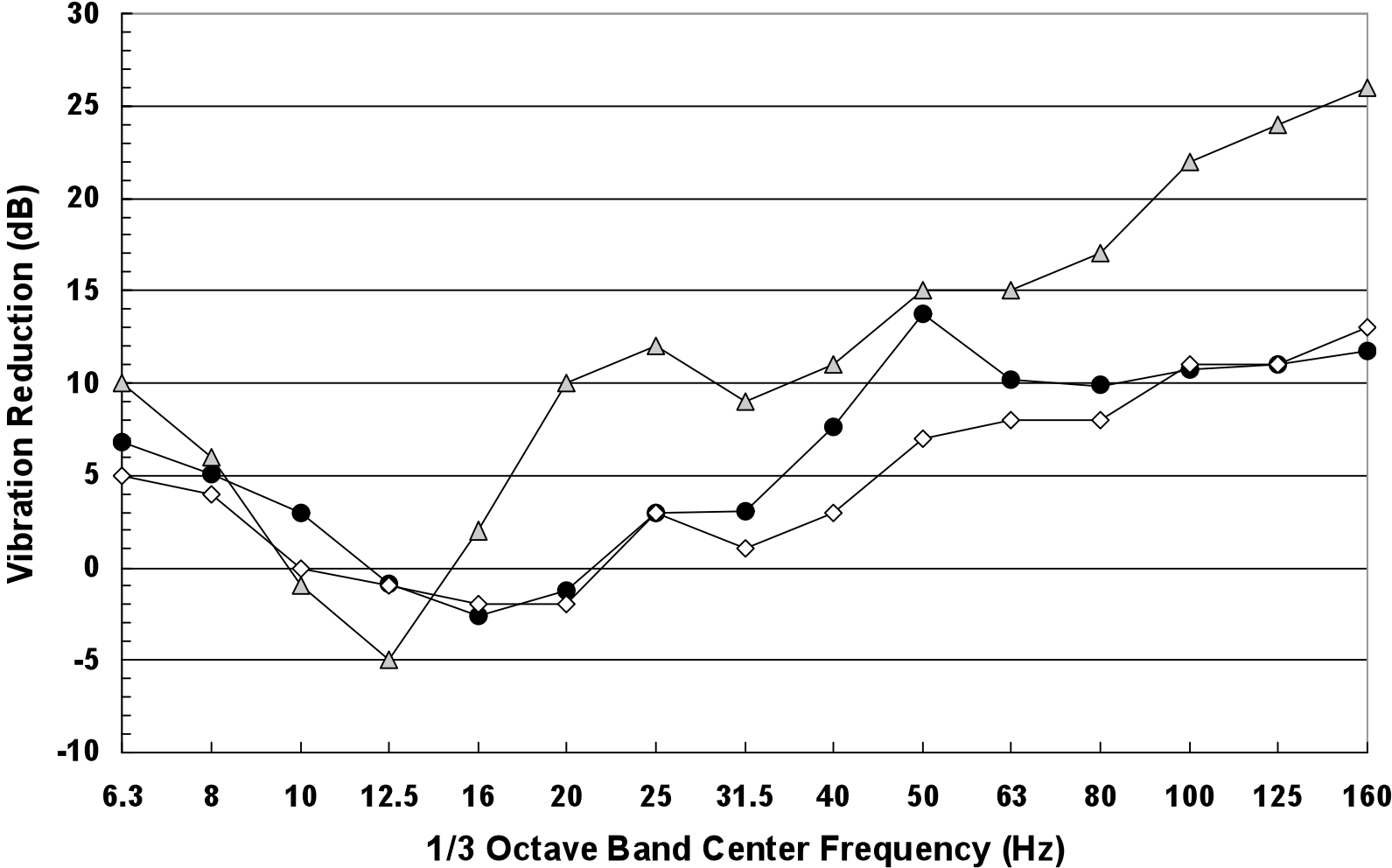
Comparison of TDA Test Results in Denver and San Jose

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Comparison of Vibration Mitigation Treatment Performance

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● TDA (Denver RTD) ◇ Ballast Mat (SF Muni) △ Floating Slab (SF Muni)

Conclusions

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- On average, the TDA underlayment at Denver RTD provides a ground-borne vibration reduction of about 3 dB between 25 Hz and 31.5 Hz and reductions of 8-14 dB between 40 Hz and 160 Hz.
- The recent TDA vibration reduction test results at Denver RTD are similar to those obtained from pre-operation tests (by Parsons, using a vibratory roller source) and to those obtained from recent TDA vibration tests (by WIA) at the VTA light rail system in San Jose, CA.
- Compared to other types of vibration mitigation measures tested (by WIA) at the San Francisco, CA Muni light rail system, the TDA vibration reduction performance at RTD was found to be equal or superior to that of a ballast mat and not as effective as a floating slab track installation.

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