

WILSON IHRIG
ACOUSTICS, NOISE & VIBRATION

RAIL TRANSIT SEMINAR



August 26-28,
2025

WRI2025RT

SEATTLE, WA

Derek Watry

Principal & President,
Wilson Ihrig





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RAIL TRANSIT SEMINAR



August 26-28,
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Katie Krainc

Associate Consultant,
Wilson Ihrig

SEATTLE, WA



WRI2025RT

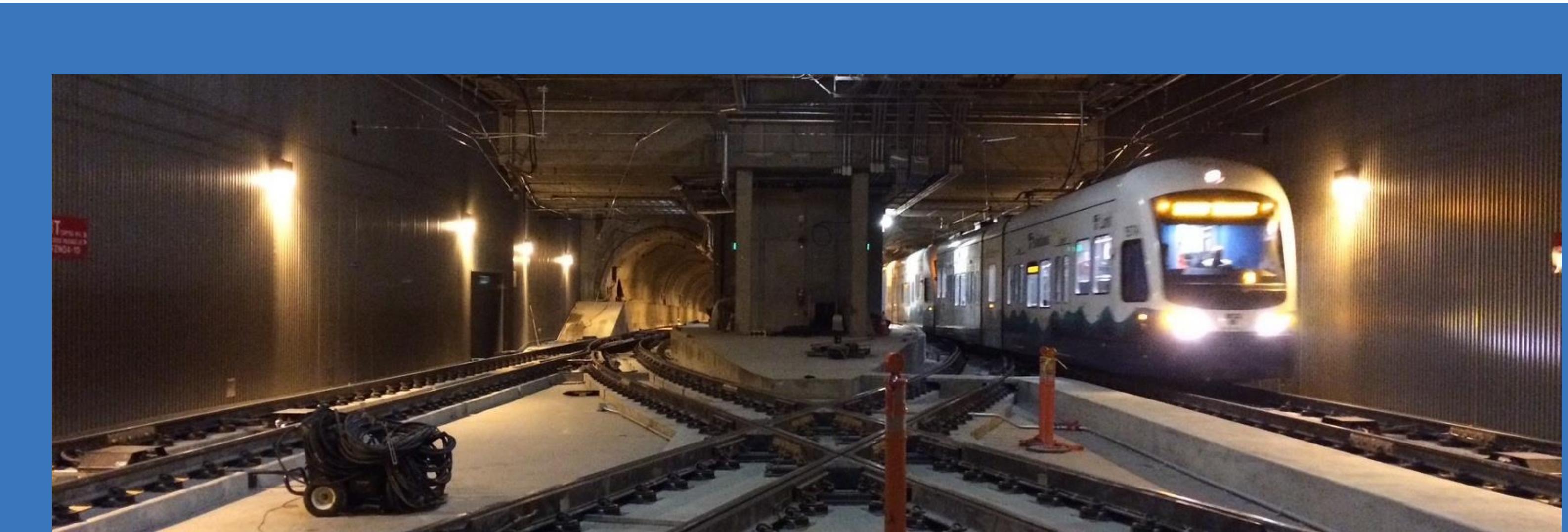


RAIL TRANSIT SEMINAR



August 26-28,
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Results to Date of Continuous Rail Vibration Monitoring at University of Washington



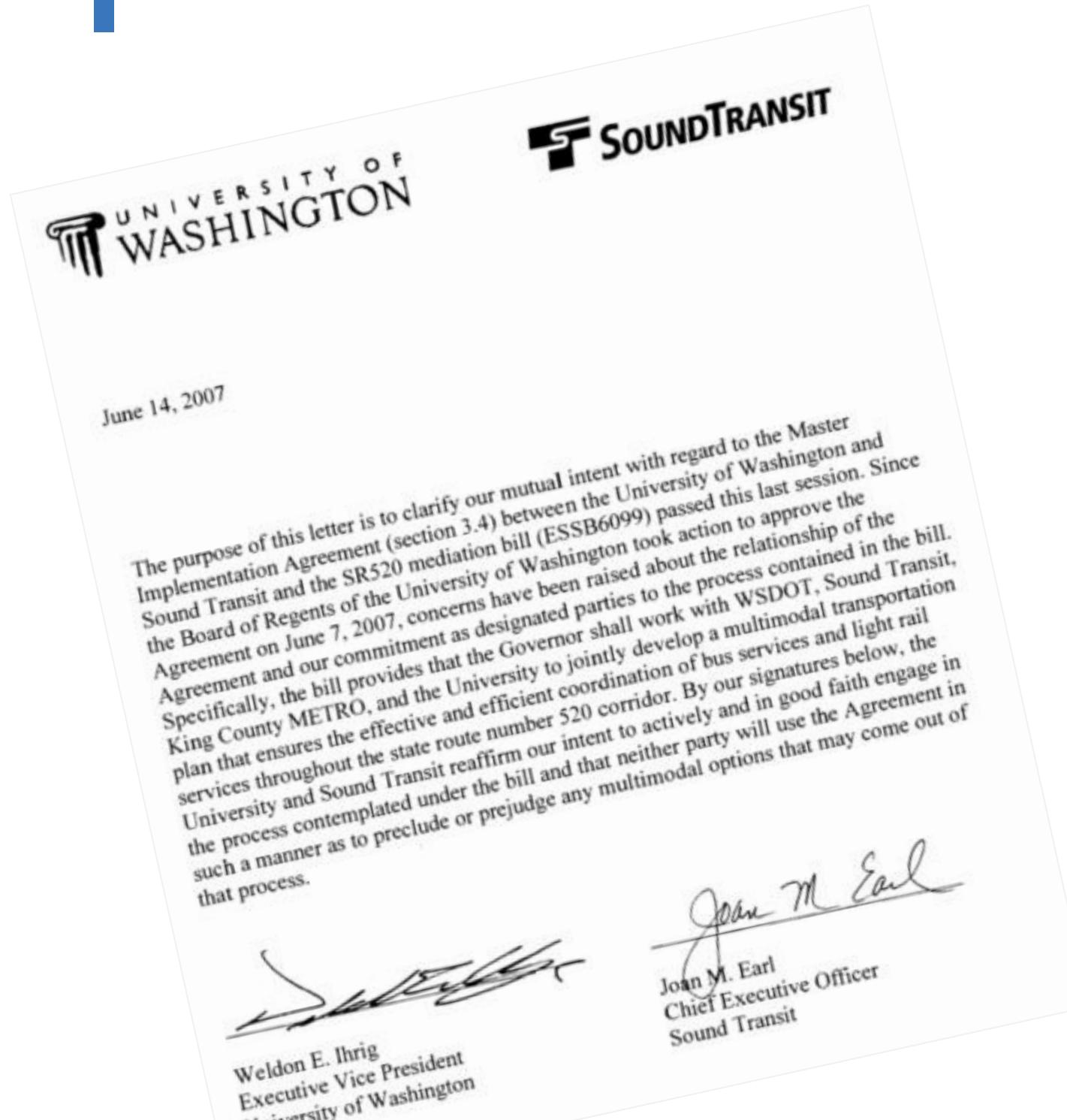
Katie Krainc & Derek Watry
Wilson Ihrig

SEATTLE, WA

WRI2025RT



Master Implementation Agreement (MIA)





Master Implementation Agreement (MIA)

UNIVERSITY OF WASHINGTTON

SOUNDTRANSIT

Section Four: Select Mitigation Conditions on Sound Transit Entry

4.1. GENERAL VIBRATION AND MF MITIGATION CONDITIONS

4.1.1. Thresholds for Specific University Buildings, Damages, Exception.

Sound Transit shall not exceed the Thresholds for vibration and MF for University buildings described in Exhibits A-1 and B-1 of this Agreement and shall be subject to any and all liquidated damages for any Exceedences thereof, PROVIDED THAT, the University shall waive such payments for Exceedances that are planned for, scheduled, and approved by the University during Sound Transit's pre-Revenue Service testing, maintenance and capital replacement. Appendices E ("Vibration Mitigation Drawing") and H ("EMI Drawing and Description of EMI Mitigation Program") of the MOA are herein voided.

June 14, 2007

The purpose of this Implementation Agreement is to implement the Board's Agreements made in the Specific Plan that will serve the University in the process such a manner as to prevent that process.

Weldon E. Ihrig
Executive Vice President
University of Washington

Joan M. Earl
Chief Executive Officer
Sound Transit

[Signatures]



Master Implementation Agreement (MIA)

UNIVERSITY OF WASH SOUNDTRANSIT

Section Four: Select Mitigation Cond

4.1. GENERAL VIBRATION AND MF MI

4.1.1. Thresholds for Specific University Buildings

Sound Transit shall not exceed the Thresholds for Specific University buildings described in Exhibit C. Buildings shall be subject to any and all liquid vibration mitigation measures provided by Sound Transit. PROVIDED THAT, the University buildings listed below that are planned for, scheduled, and/or under construction during Sound Transit's pre-ReRevenue Service test period, shall be subject to the vibration thresholds described in Appendices E ("Vibration Mitigation Procedure") and F ("Description of EMI Mitigation Procedure").

The purpose of this Addendum is to implement the Master Implementation Agreement between Sound Transit and the Board of Regents of the University of Washington. It amends the Master Implementation Agreement, dated January 1, 2007, between Sound Transit and the Board of Regents of the University of Washington. This Addendum is effective as of the date of execution of this Addendum. All other rights are retained.

June 14, 2007

Weldon E. Ihrig
Executive Vice President
University of Washington

John M. Earl
Chief Executive Officer
Sound Transit

**Exhibit C
Preferred Alternative Alignment Map**

University of Washington Buildings

- A. Bagley Hall
- B. Benson Hall
- C. Bioengineering/Genomics
- D. Burke Museum
- E. Center on Human Development and Disability (CHDD)
- F. Chemistry
- G. Health Sciences Imaging Center
- H. Electrical Engineering/Computer Science
- I. Fisheries Center (CMBL)
- J. Fisheries Sciences
- K. Fisheries Teaching and Research Center
- L. Fluke Hall
- M. Henderson Hall
- N. Johnson Hall
- O. Marine Sciences (MMBL)
- P. Manne Studies
- Q. Mechanical Engineering and Annex
- R. More Hall
- S. Oceanography Research Building
- T. Ocean Sciences
- U. Physics/Astronomy
- V. Roberts Hall
- W. Surgery Pavilion
- X. UW Medical Center-Cyclotron
- Y. Wilcox Hall
- Z. Winkenwerder Hall

Legend:

- Stations
- Crossover
- Preferred Alternative



Master Implementation Agreement (MIA)



4.1.4. Monitoring Program. Prior to construction of the Light Rail Transit System, the Parties shall jointly develop a detailed vibration and MF monitoring program to identify, measure and report on if and when a Threshold Exceedance occurs that is directly attributable to the Light Rail Transit System. The details of the monitoring program shall be memorialized in an Operating Agreement, PROVIDED THAT said Operating Agreement shall require that the monitoring program: be developed at Sound Transit expense; include early warning vibration detectors north and south of University Property; provide data that is auditable by the Parties in real time; is highly reliable; is acceptable to the University; is installed prior to Revenue Service for each segment of newly constructed Light Rail Transit System on University Properties; and is capable of identifying long term trends of increased average and peak vibration and MF levels over time attributable to the general degradation of the Light Rail Transit System.



Weldon E. Ihrig
Executive Vice President
University of Washington

Sound Trans*



Crossover

A. Health Sciences Imaging Center
B. Electrical Engineering/Computer Science
C. Fisheries Center (CMBL)
D. Fisheries Sciences
E. Fisheries Teaching and Research Center
F. Fluke Hall
G. Henderson Hall
H. More Hall
I. Oceanography Research Building
J. Ocean Sciences
K. Physics/Astronomy
L. Roberts Hall
M. Surgery Pavilion
N. UW Medical Center-Cyclotron
O. Wilcox Hall
P. Winkenwerder Hall

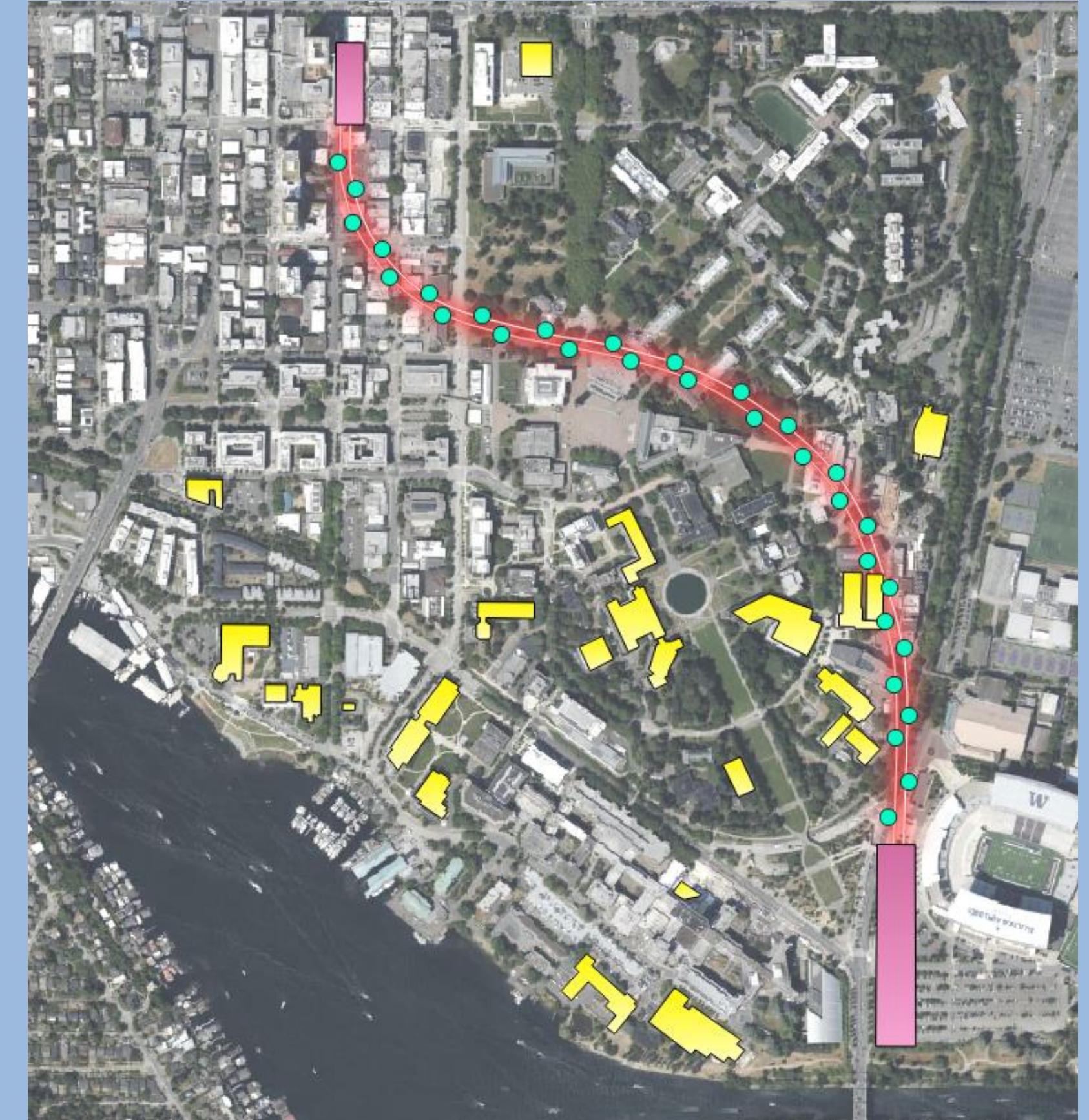
Preferred Alternative

Exhibit C
Preferred Alternative
Alignment Map



Sensitive University Buildings

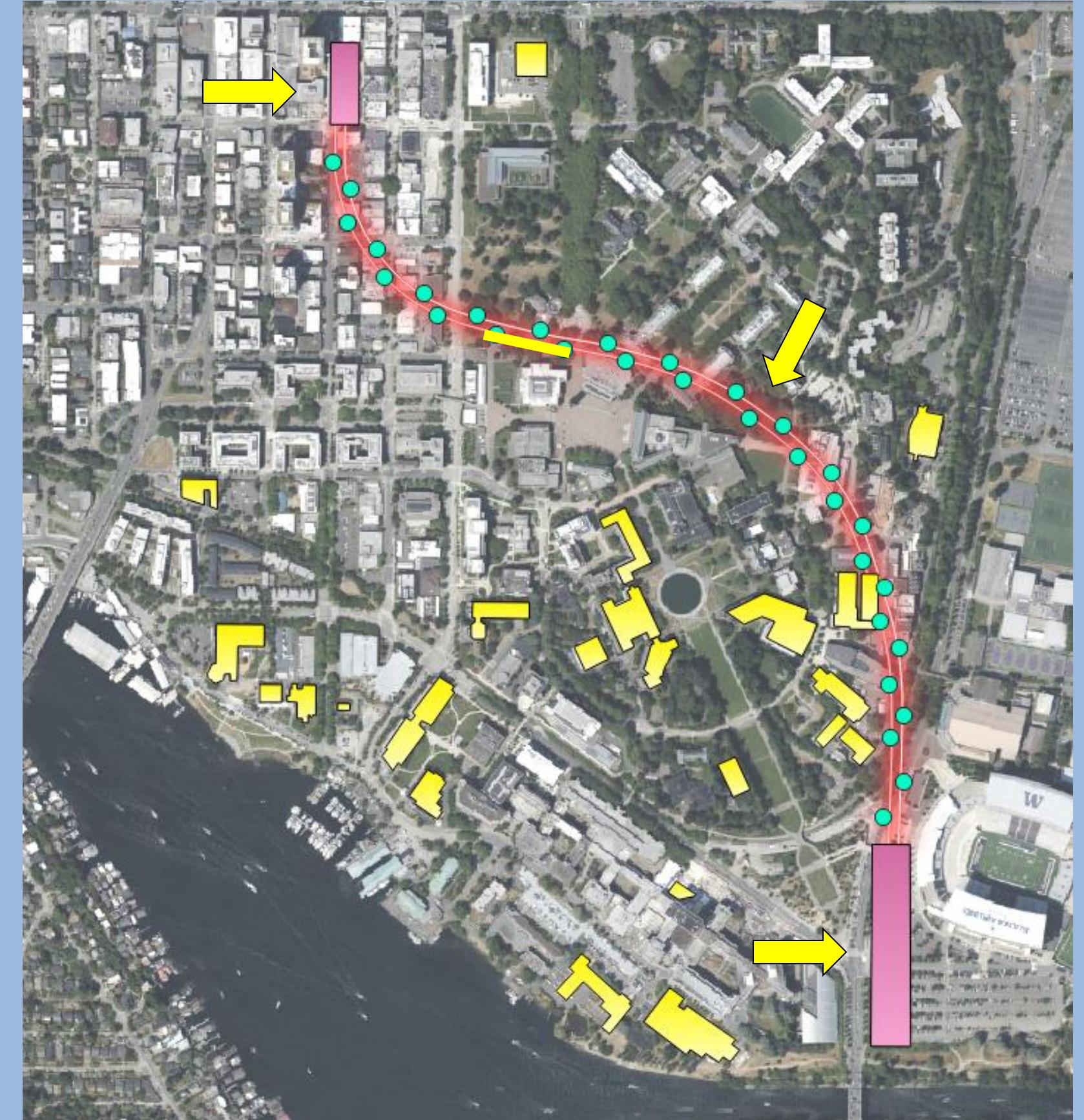
- University of Washington Station to U District Station
- 24 sensitive buildings
- 31 monitors





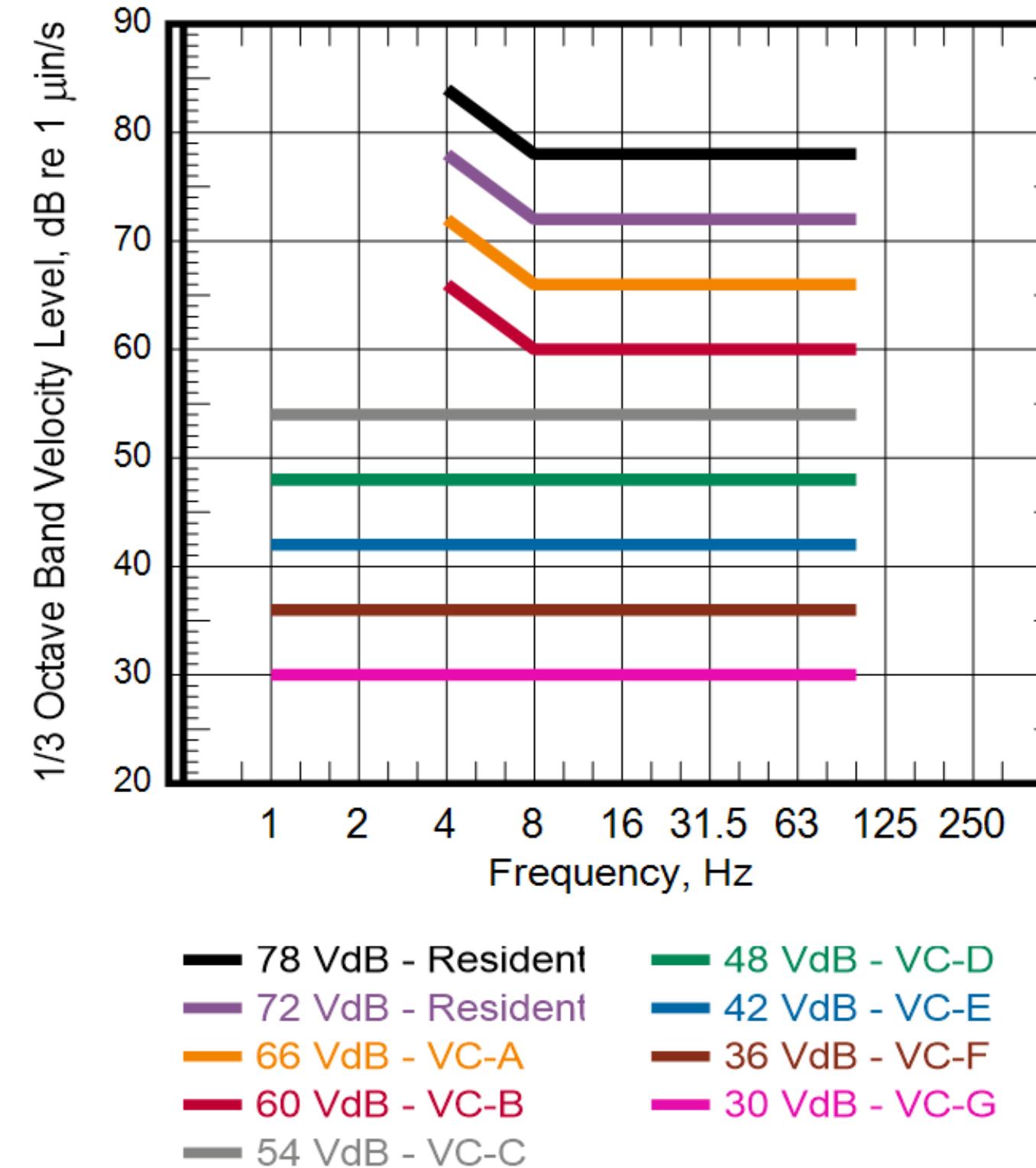
Sensitive University Buildings

- University of Washington Station to U District Station
- 24 sensitive buildings
- 31 monitors





Range of Vibration Criteria

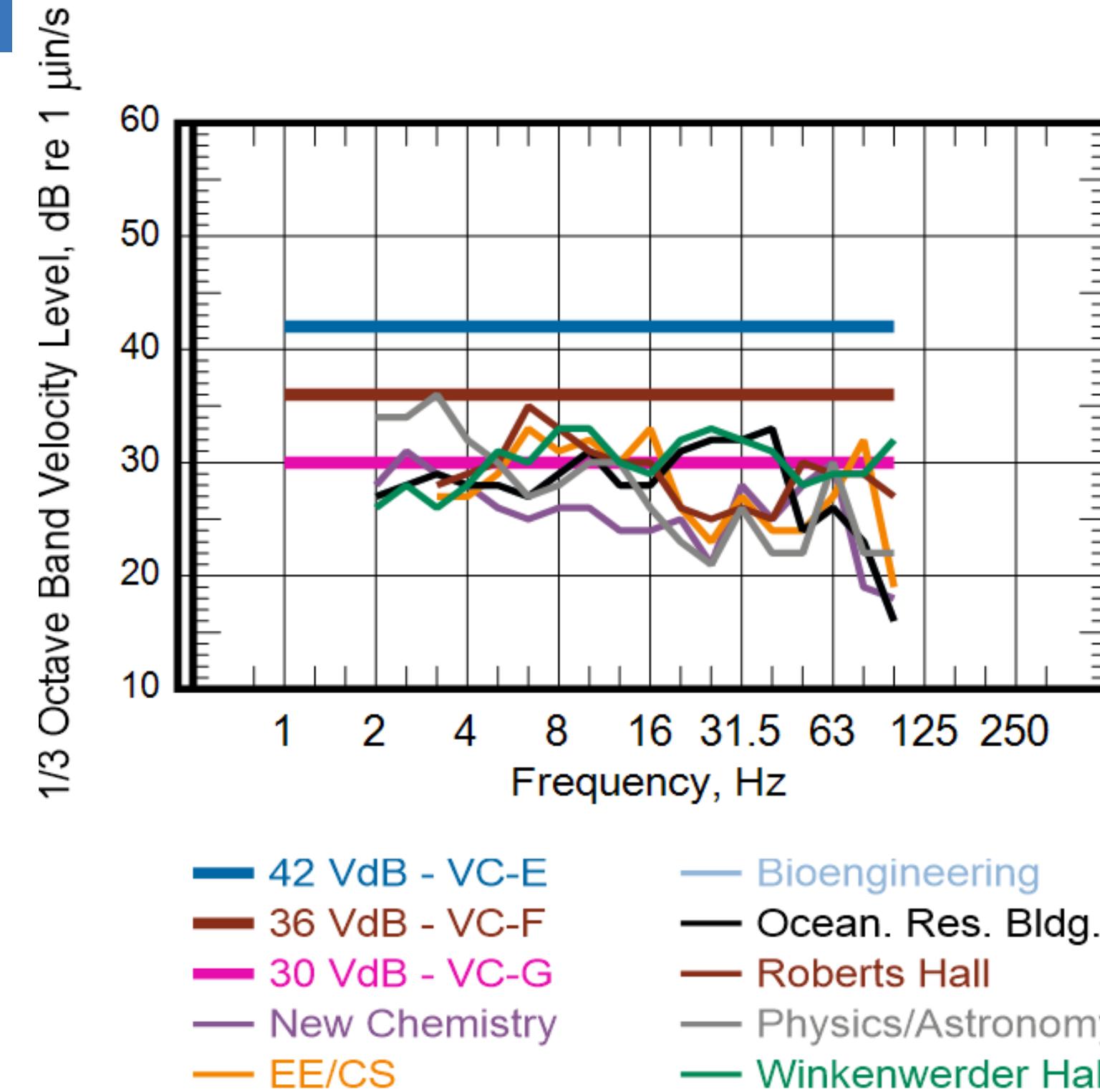


VC-F & VC-G

Extremely quiet research spaces;
not recommended as a design criterion, only for evaluations



MIA Thresholds



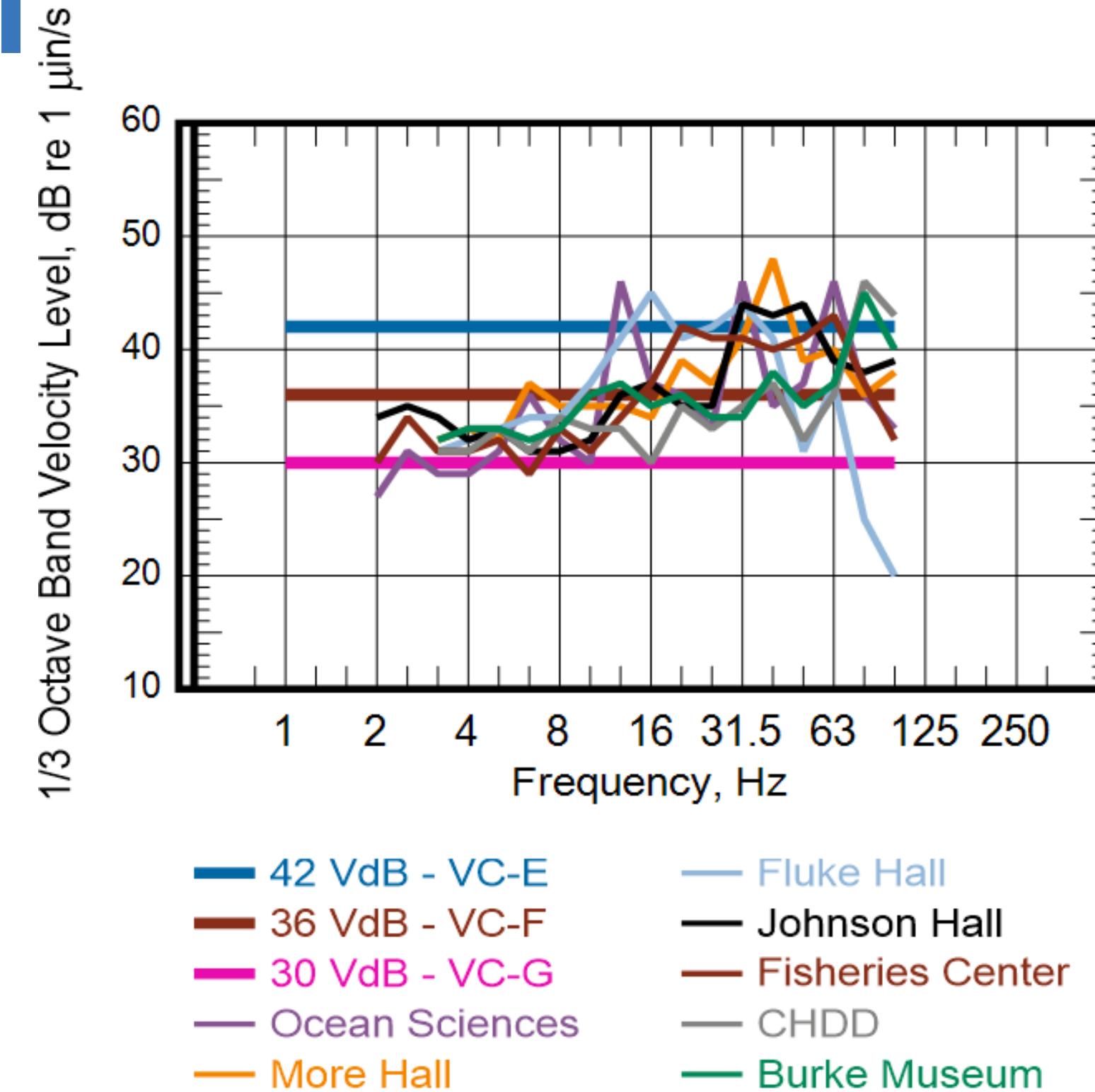
Most restrictive

Buildings with
lowest thresholds

Lower than VC-G



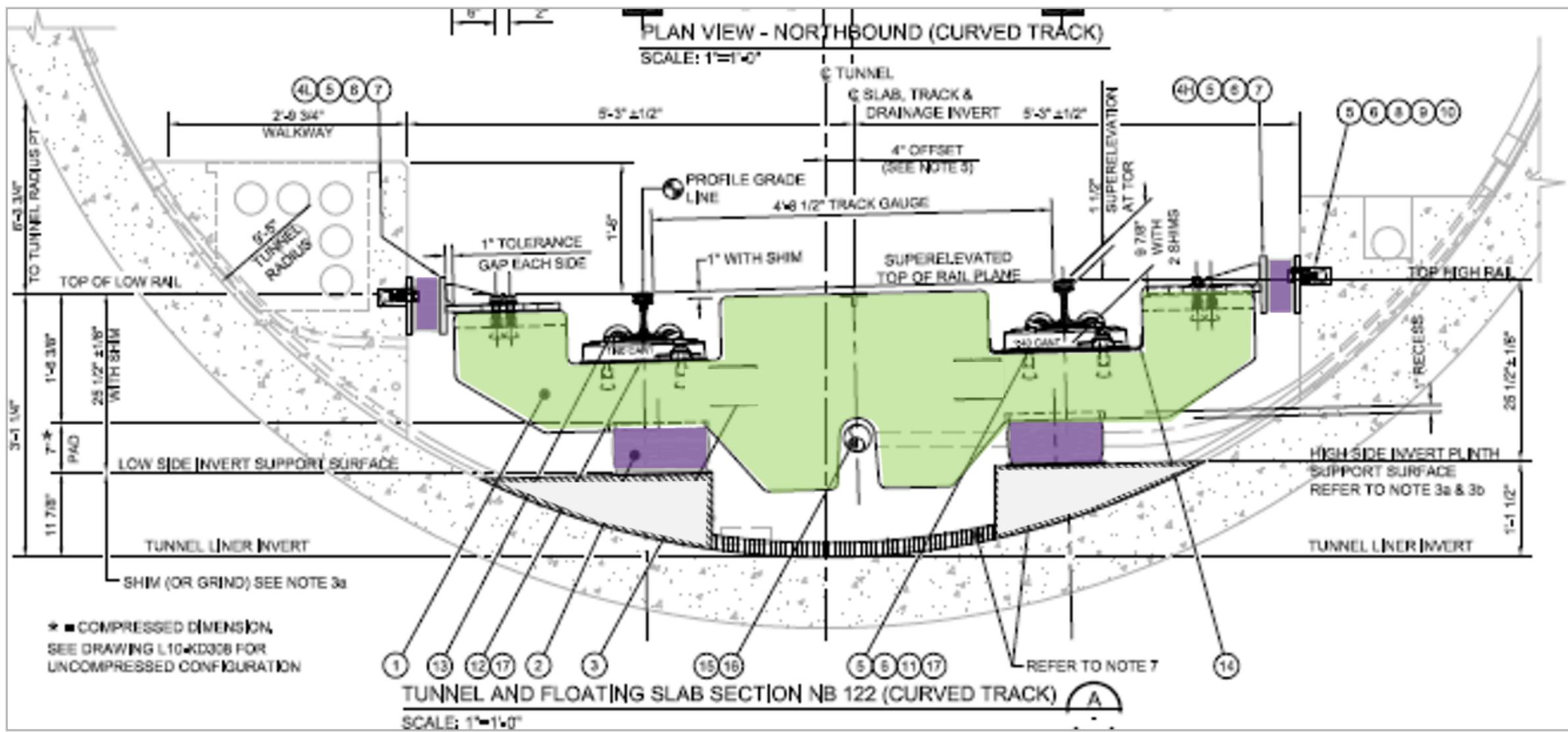
MIA Thresholds



Least restrictive
Buildings with
highest
thresholds



5 Hz Floating Slab

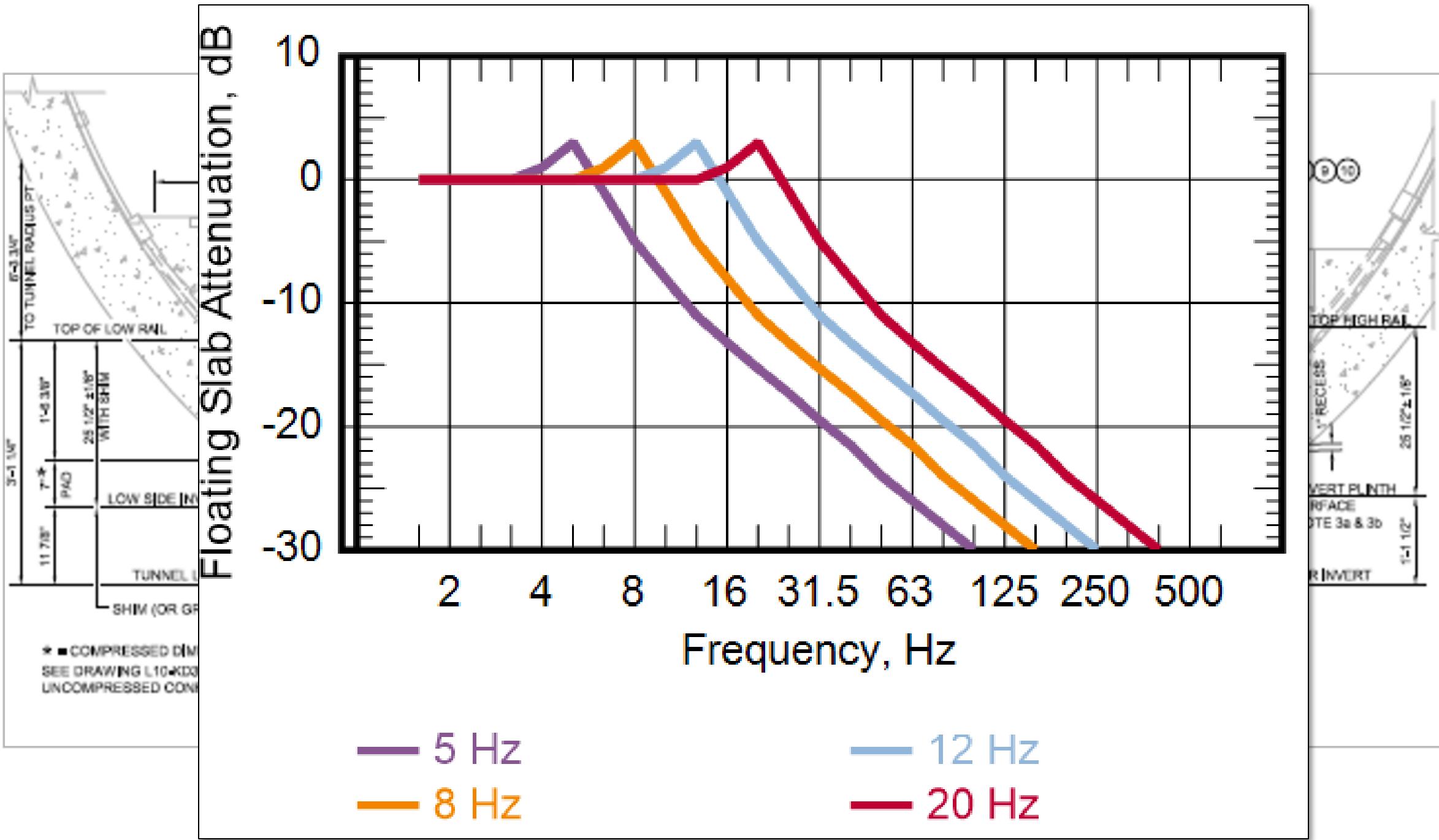


Additional factors

- Ultra-straight rail
- Grinding program
- Vehicle FDL specifications



5 Hz Floating Slab



Additional factors

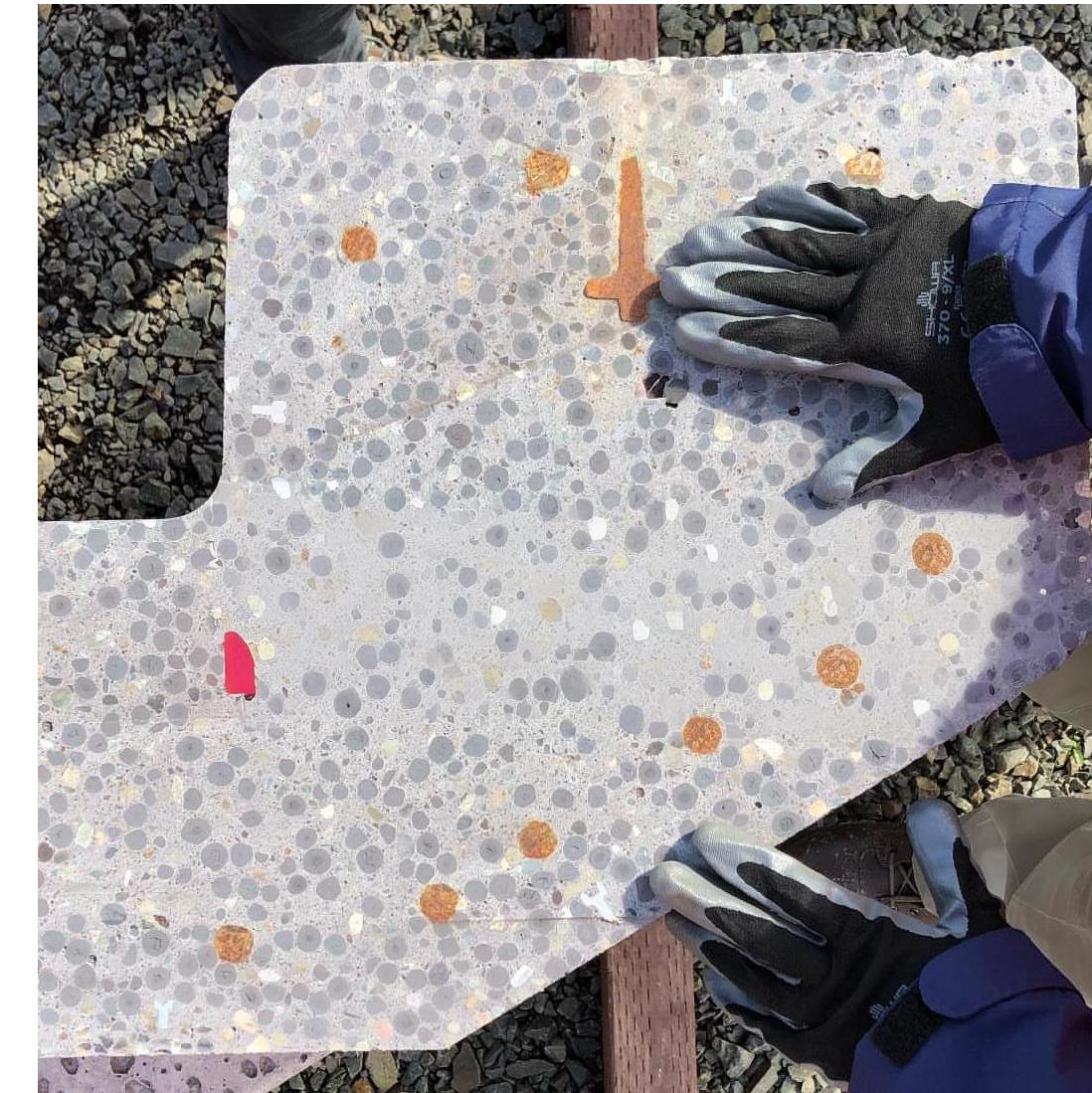
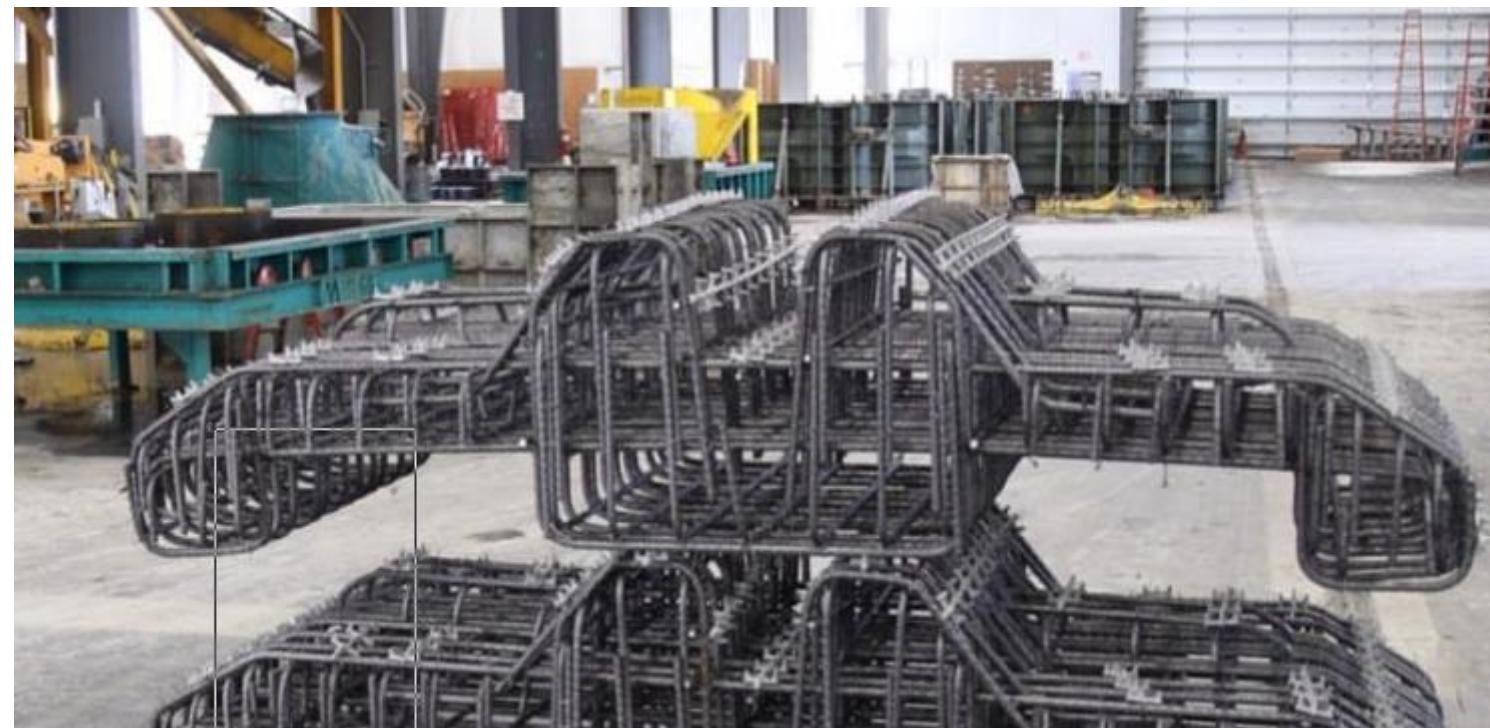
Ultra-straight rail

Grinding program

Vehicle FDL specifications



5 Hz Floating Slab





2025



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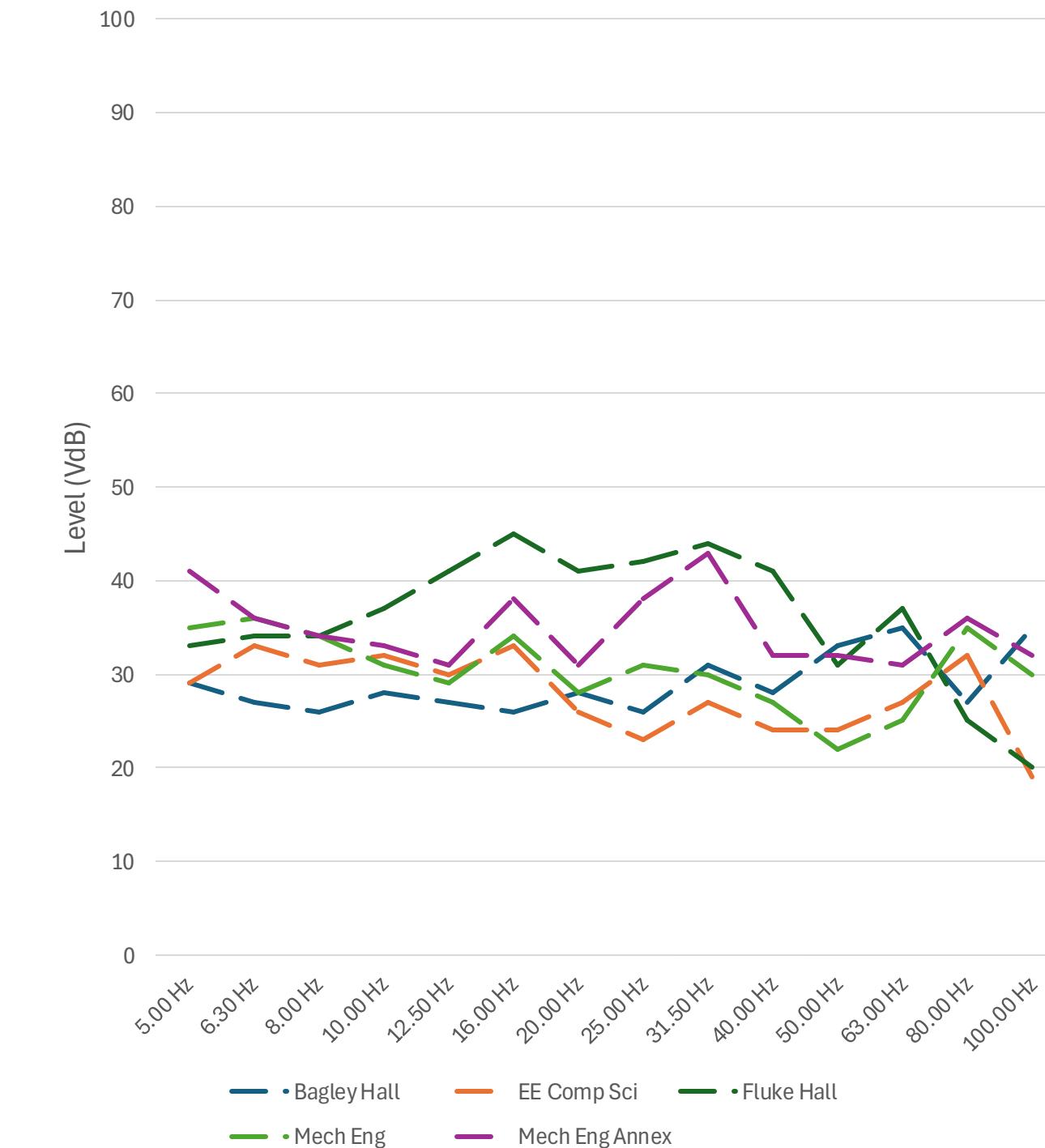
5 Hz Floating Slab





Vibration Adjustment Estimate (VAE)

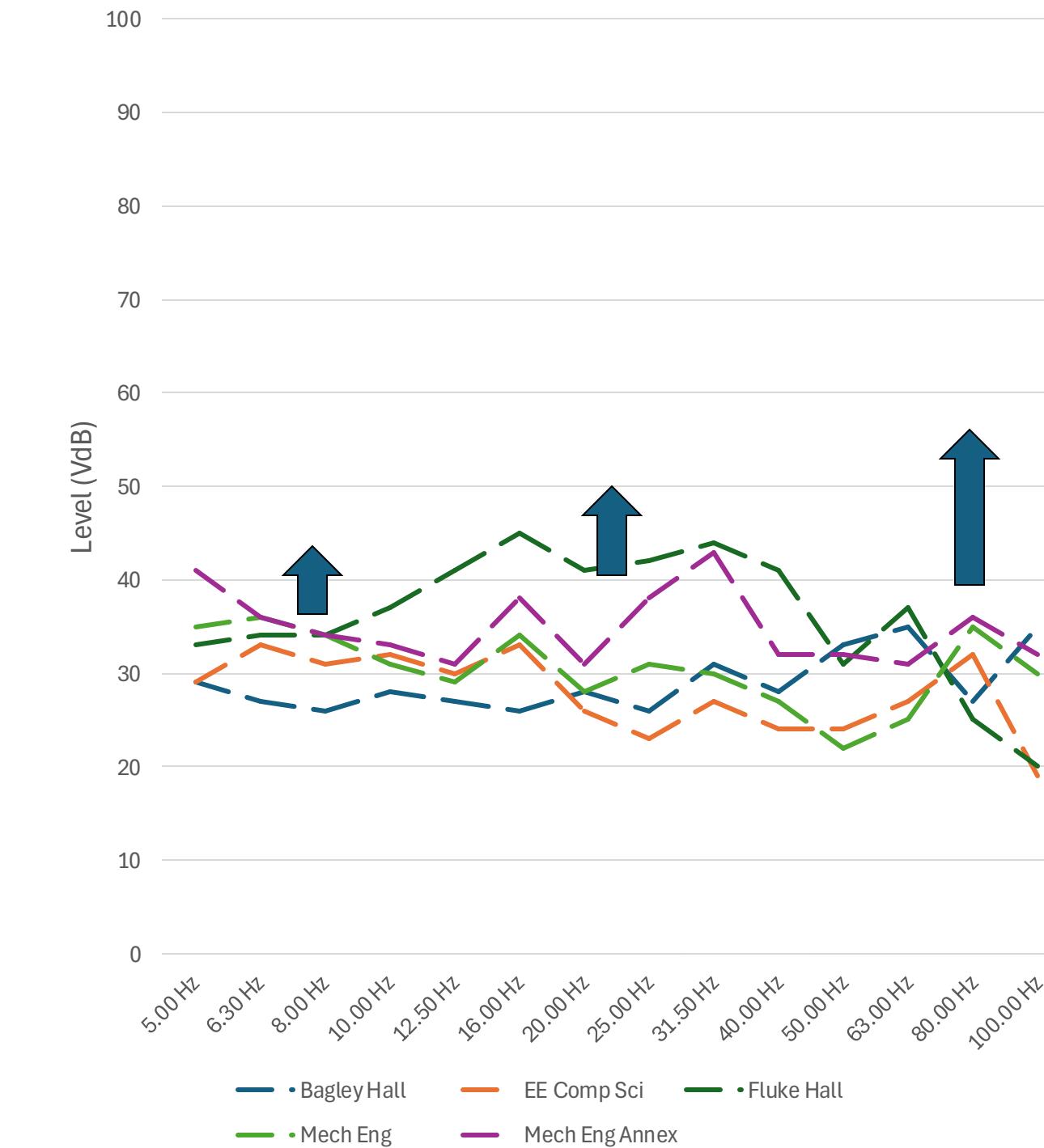
- Criteria at buildings





Vibration Adjustment Estimate (VAE)

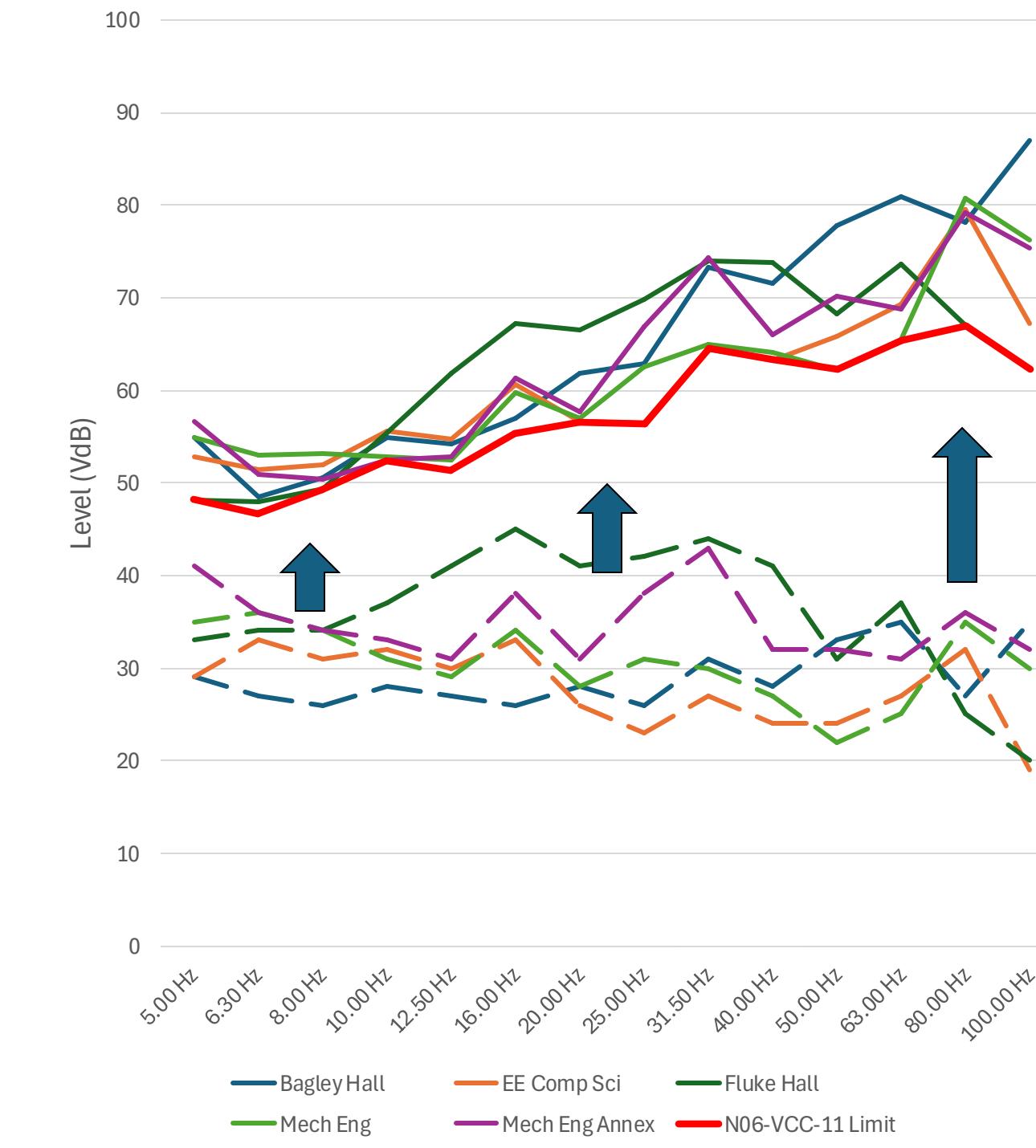
- Criteria at buildings
- Apply VAE





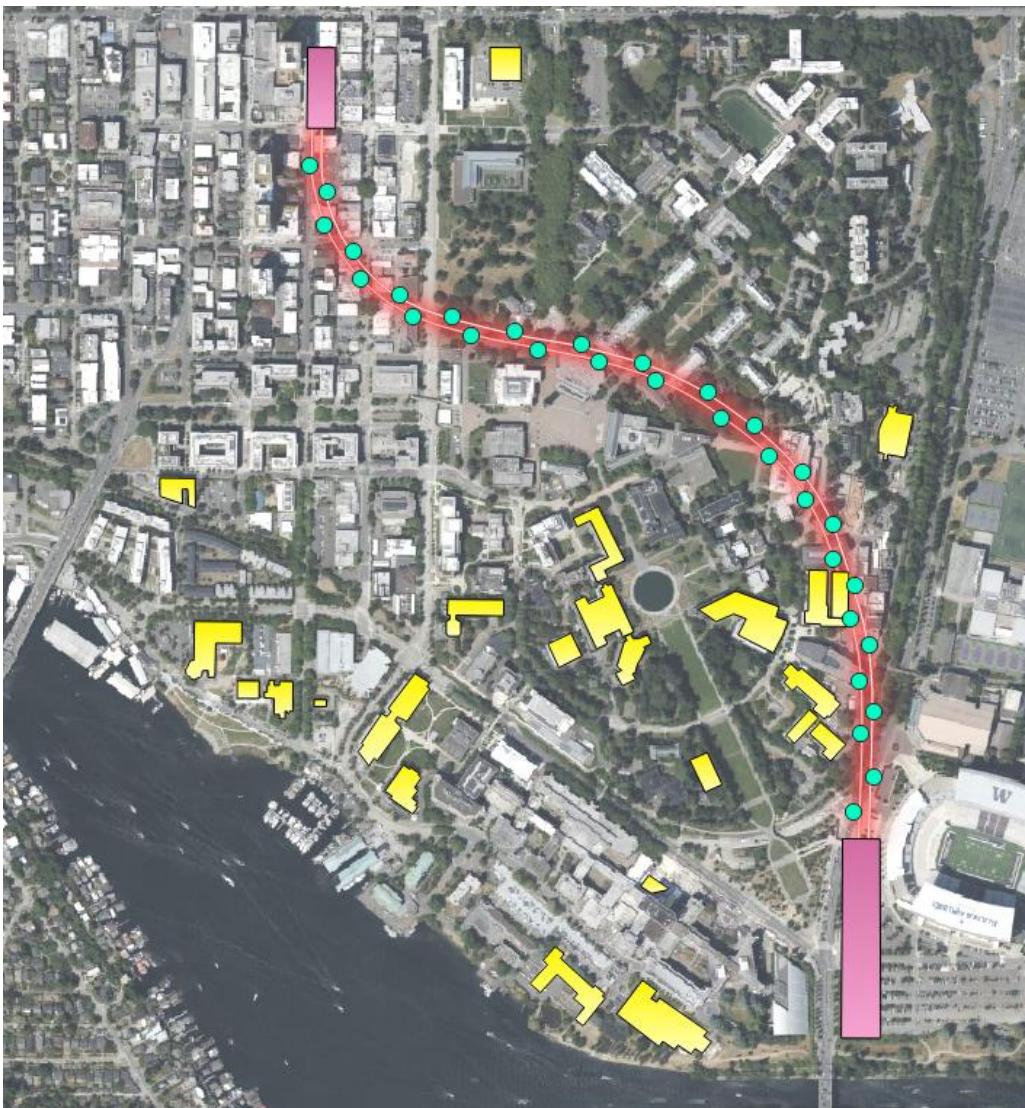
Vibration Adjustment Estimate (VAE)

- Criteria at buildings
- Apply VAE
- Criteria at monitor





31 monitor locations with redundant pairs



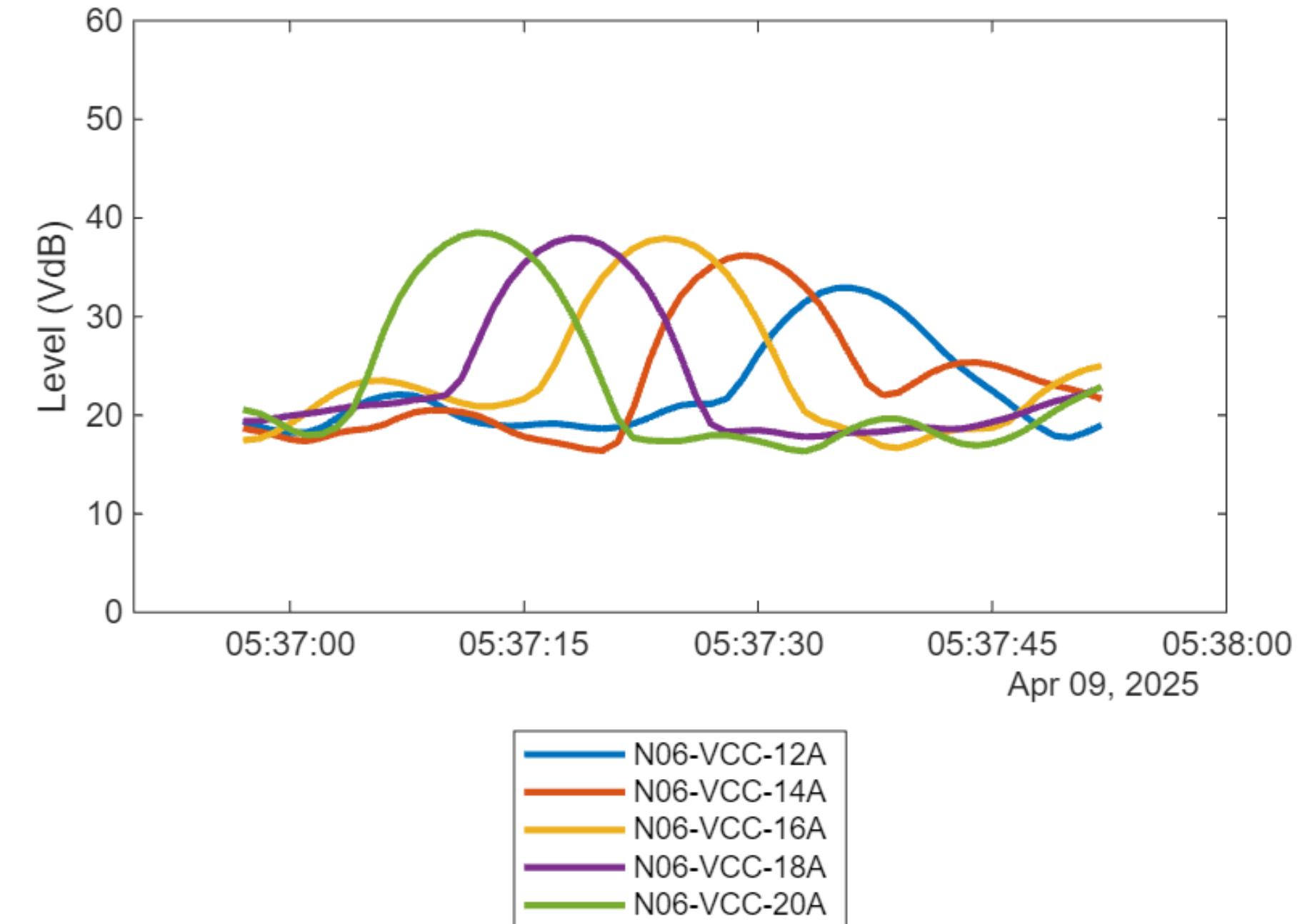


Monitoring system

- 31 monitor locations
- 2 Hz – 100 Hz in 1/3-octave bands
- VAE adjustment
- Continuous monitoring
- Warning & exceedance alarms
- Wheel flat detector



Single passby (5 Hz)

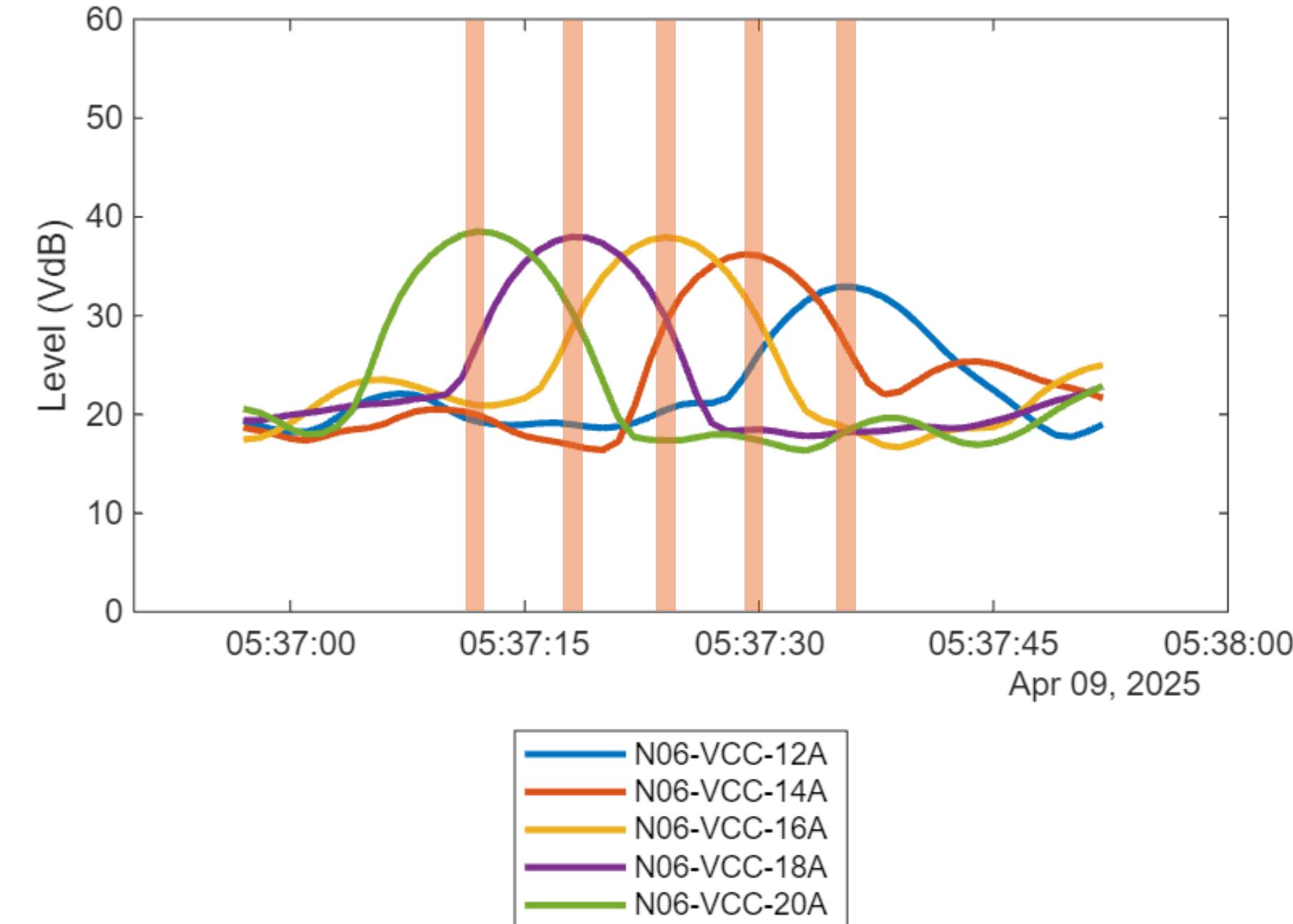


Monitors 12-20

Southbound,
track on floating
slab



Single passby (5 Hz)

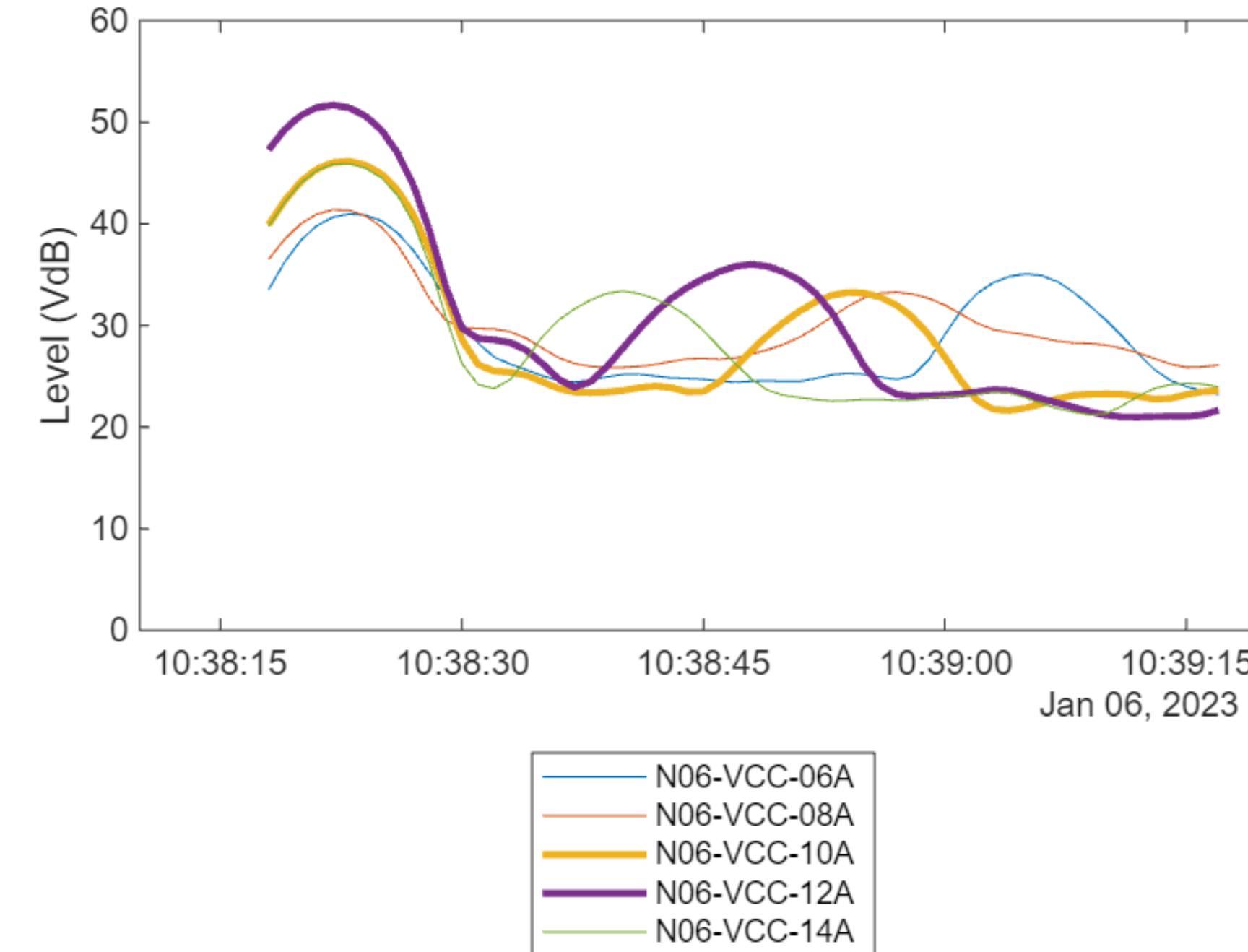


Monitors 12-20

Southbound,
track on floating
slab



Non-train exceedances



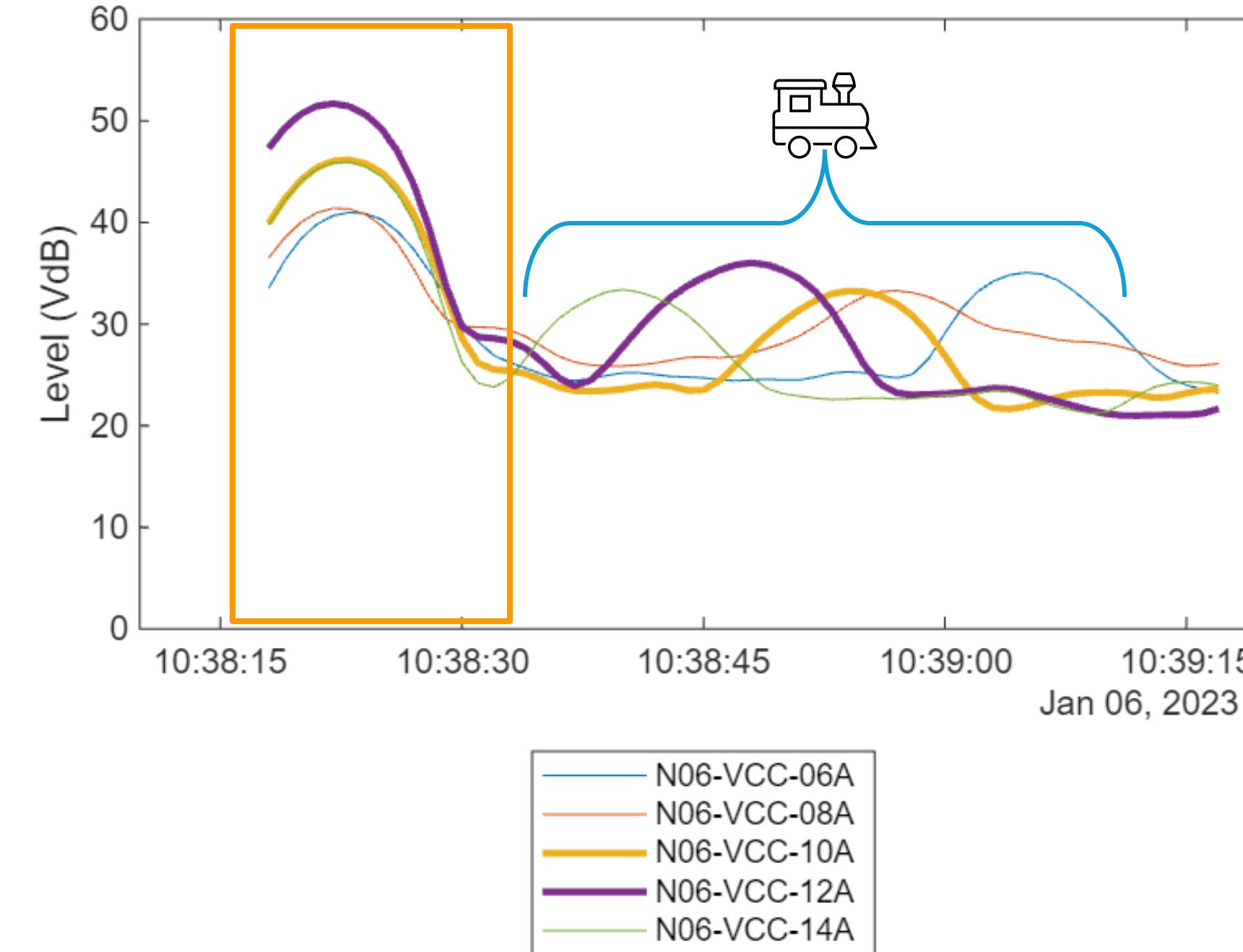
Monitors 6-14, 6.3
Hz

Southbound,
track on floating
slab

Exceedance
triggered at
Monitors 10 & 12



Non-train exceedances

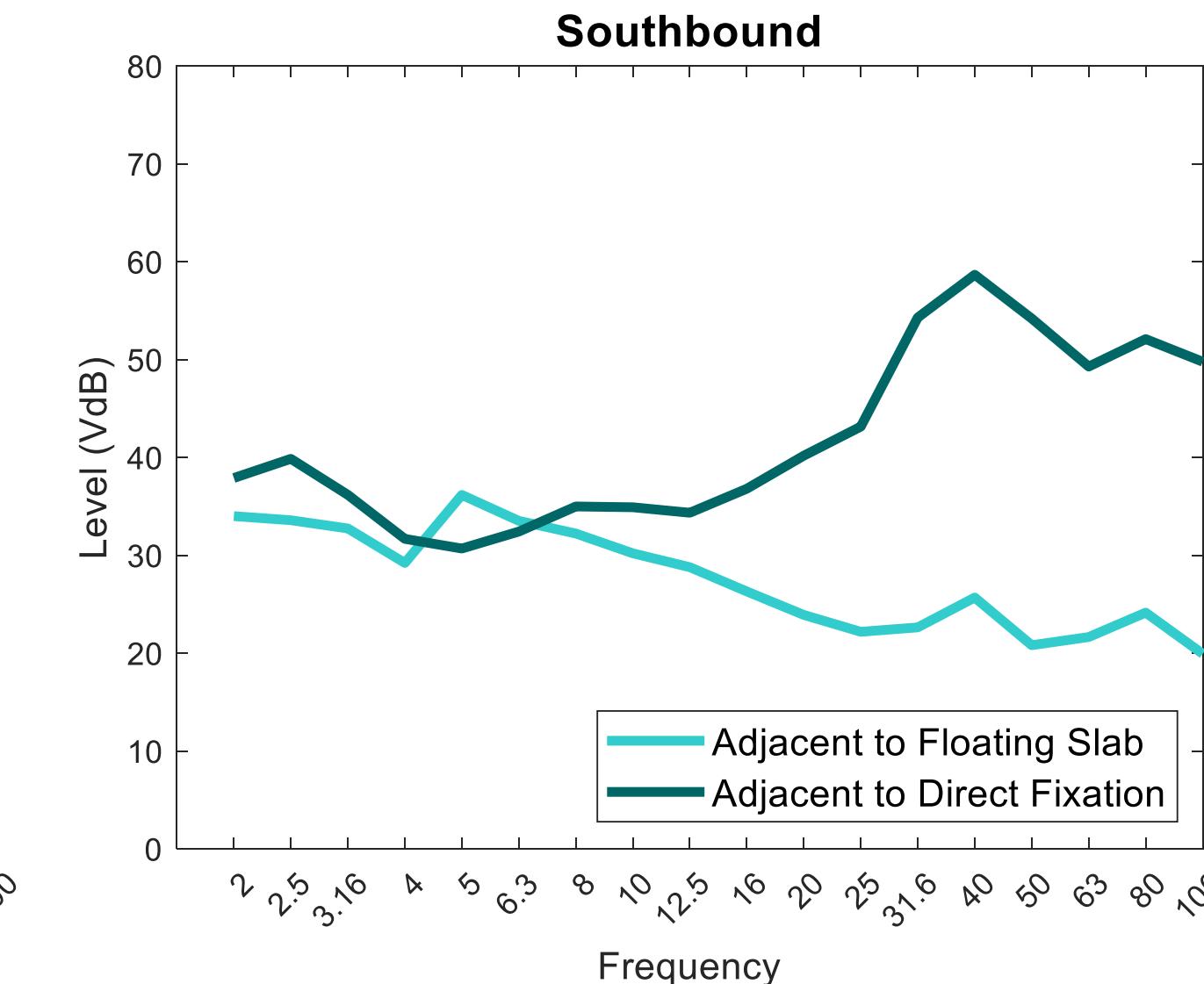
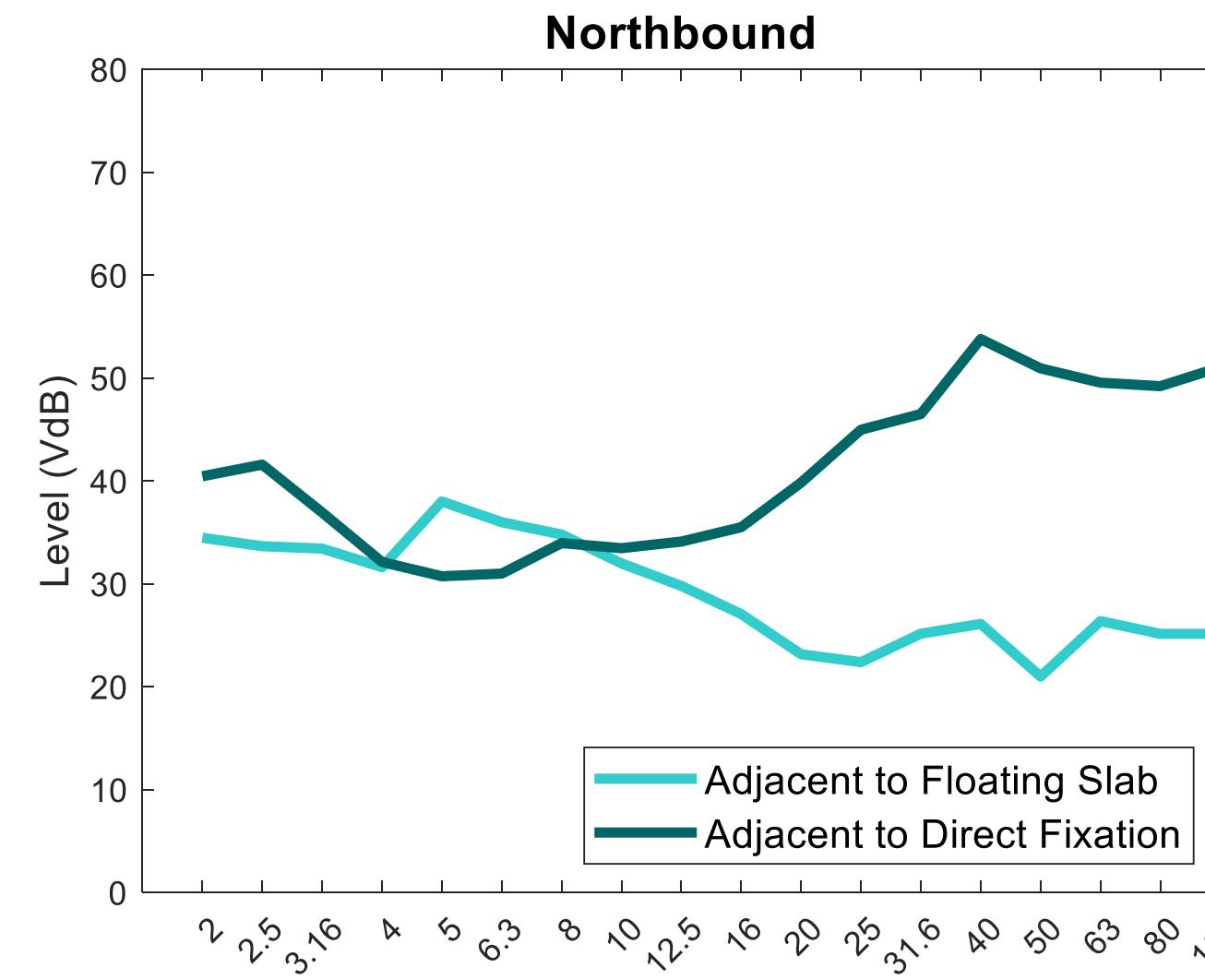


Monitors 6-14, 6.3 Hz
Southbound,
track on floating slab
Exceedance triggered at Monitors 10 & 12



Track on Floating Slab vs Direct Fixation

- Vibration is overall higher off of 5 Hz floating slab
- On 5 Hz floating slab there is a peak at the 5 Hz resonant frequency, but higher frequency vibration is attenuated

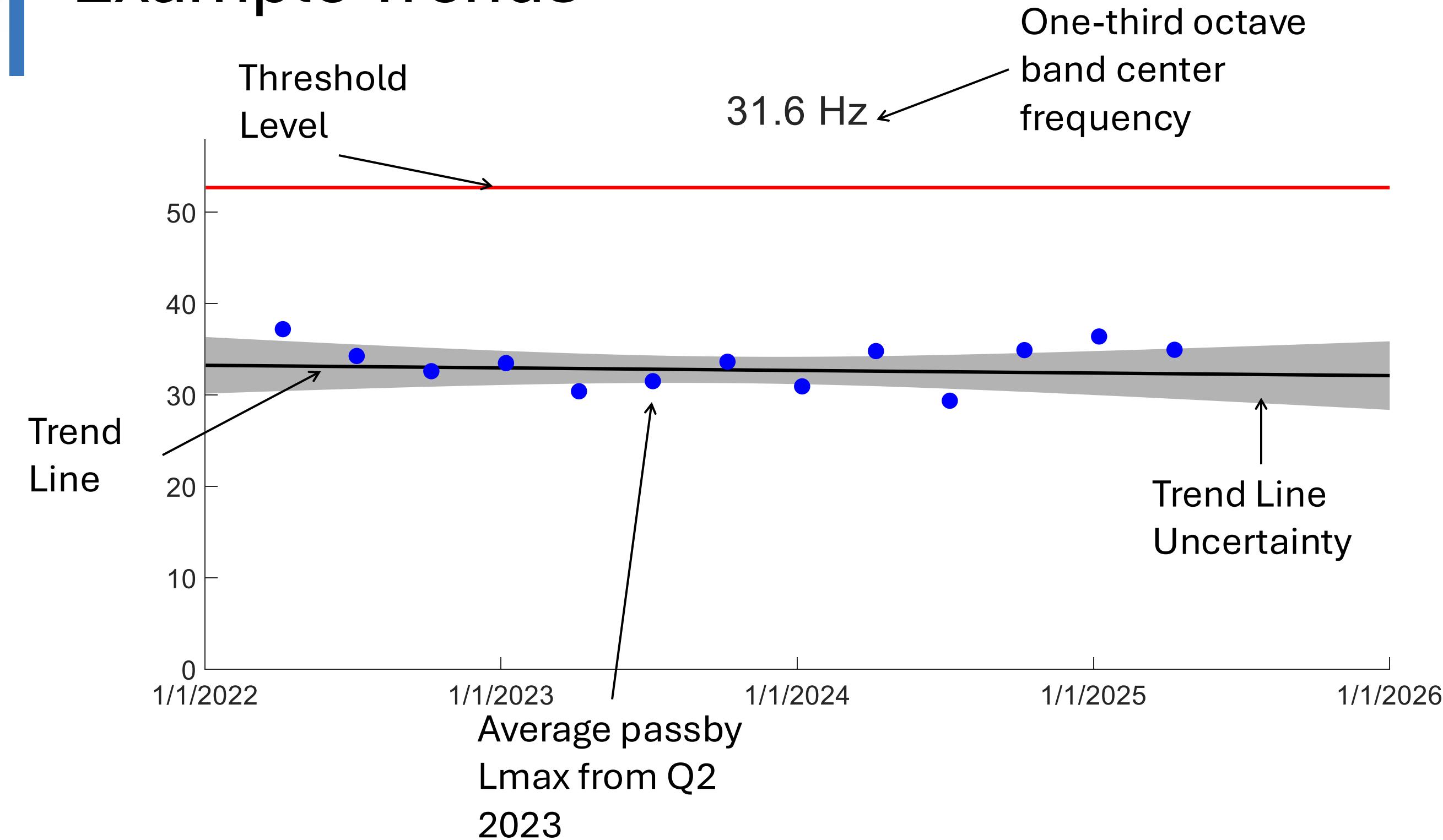


Trend Analysis

- Quarterly trend analysis
- Data from 2022 – present
- Pull 24h of data from the monitoring system each quarter
- Report & analyze data for each monitor at each frequency

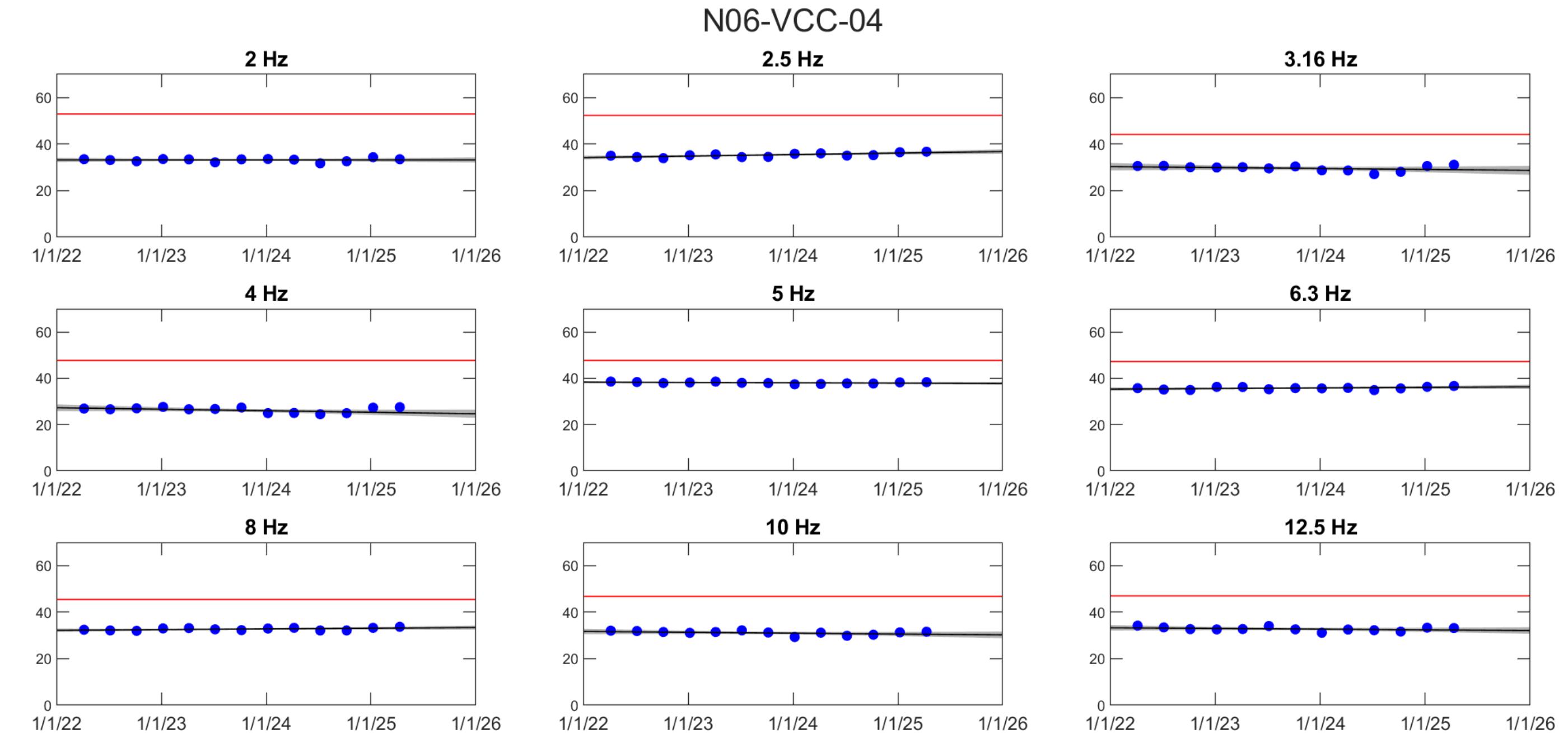


Example Trends



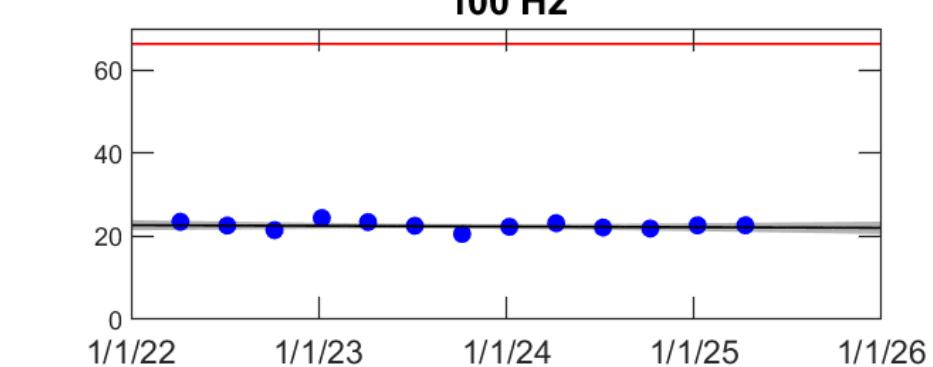
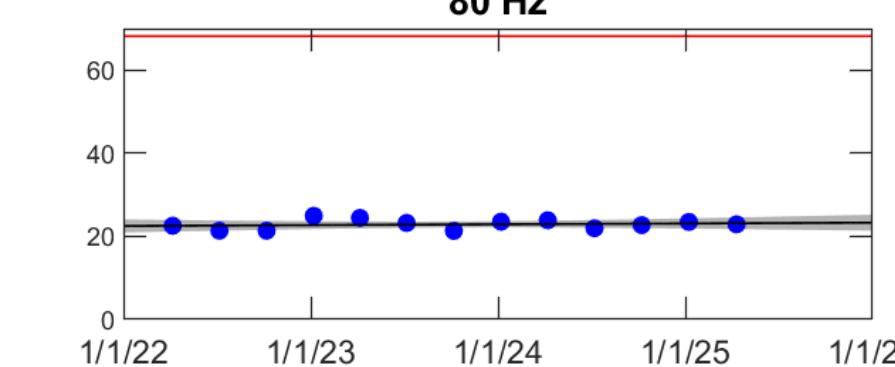
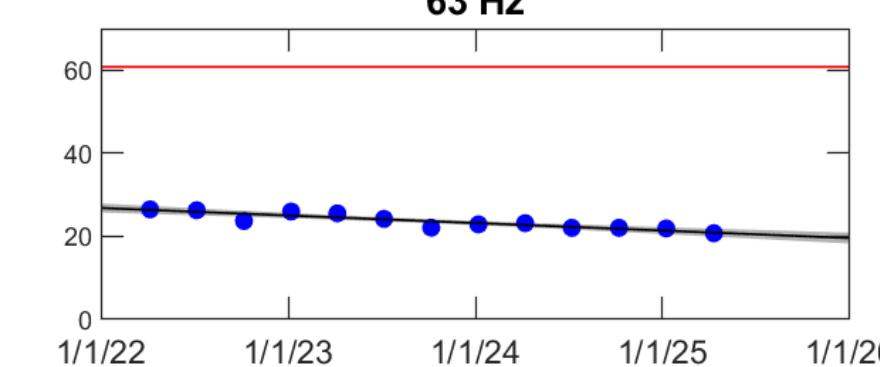
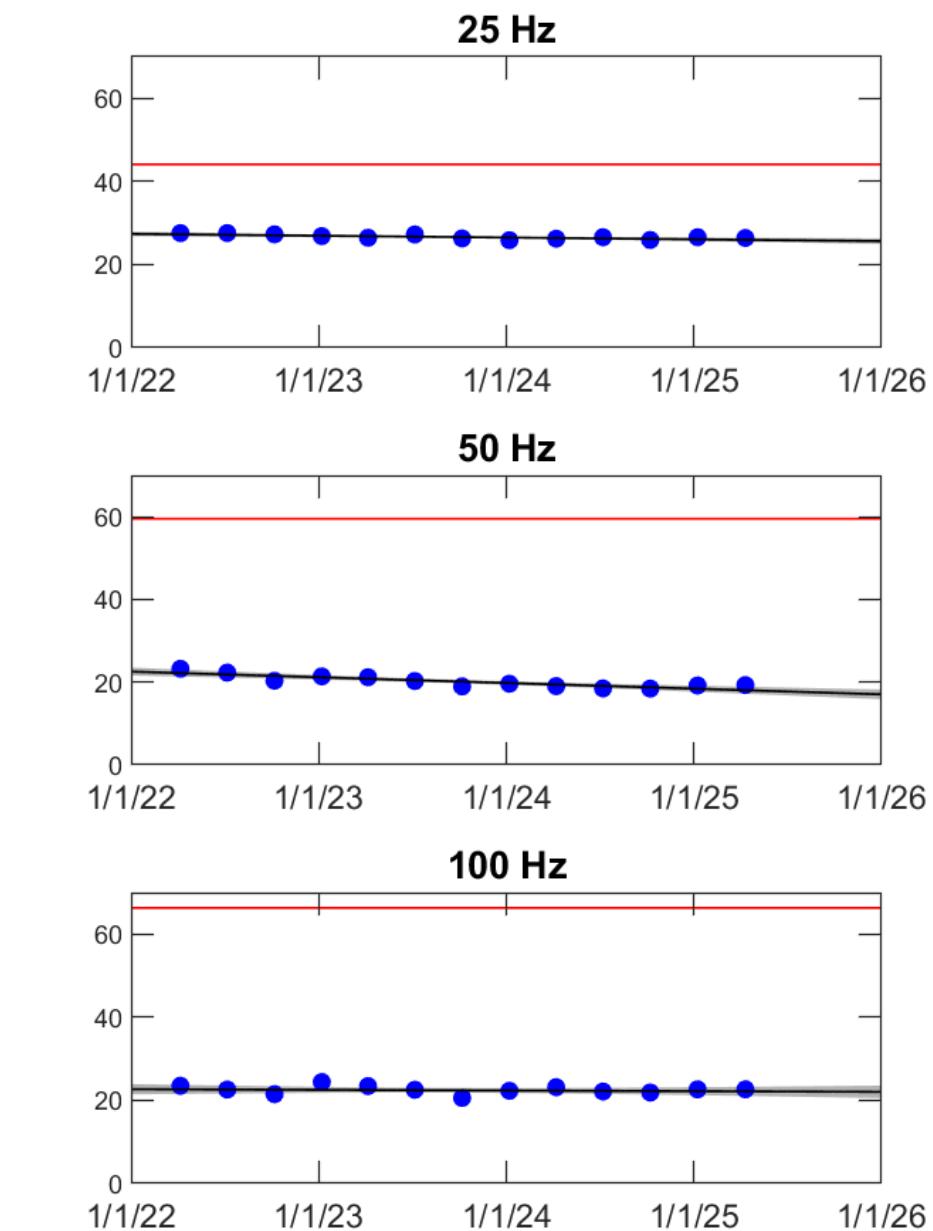
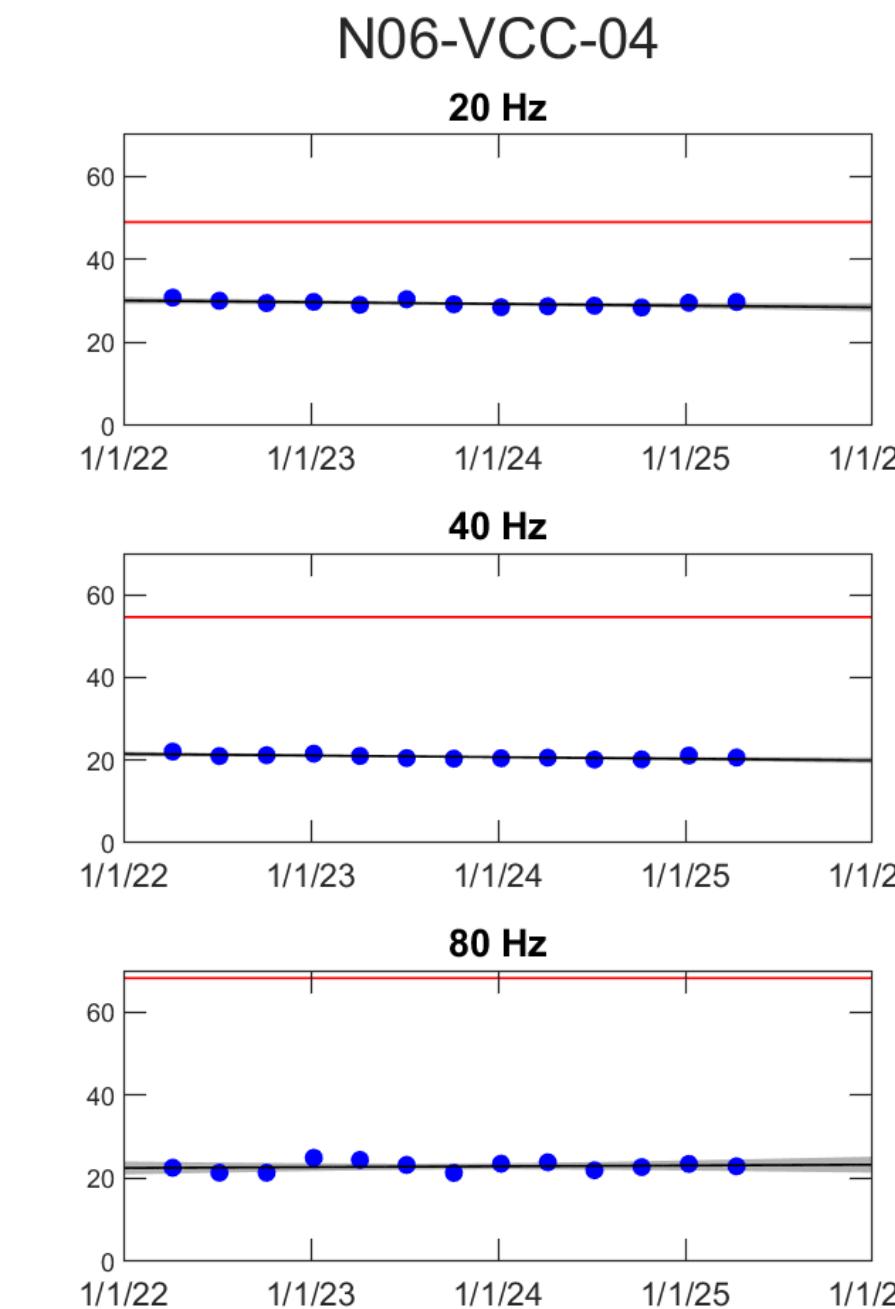
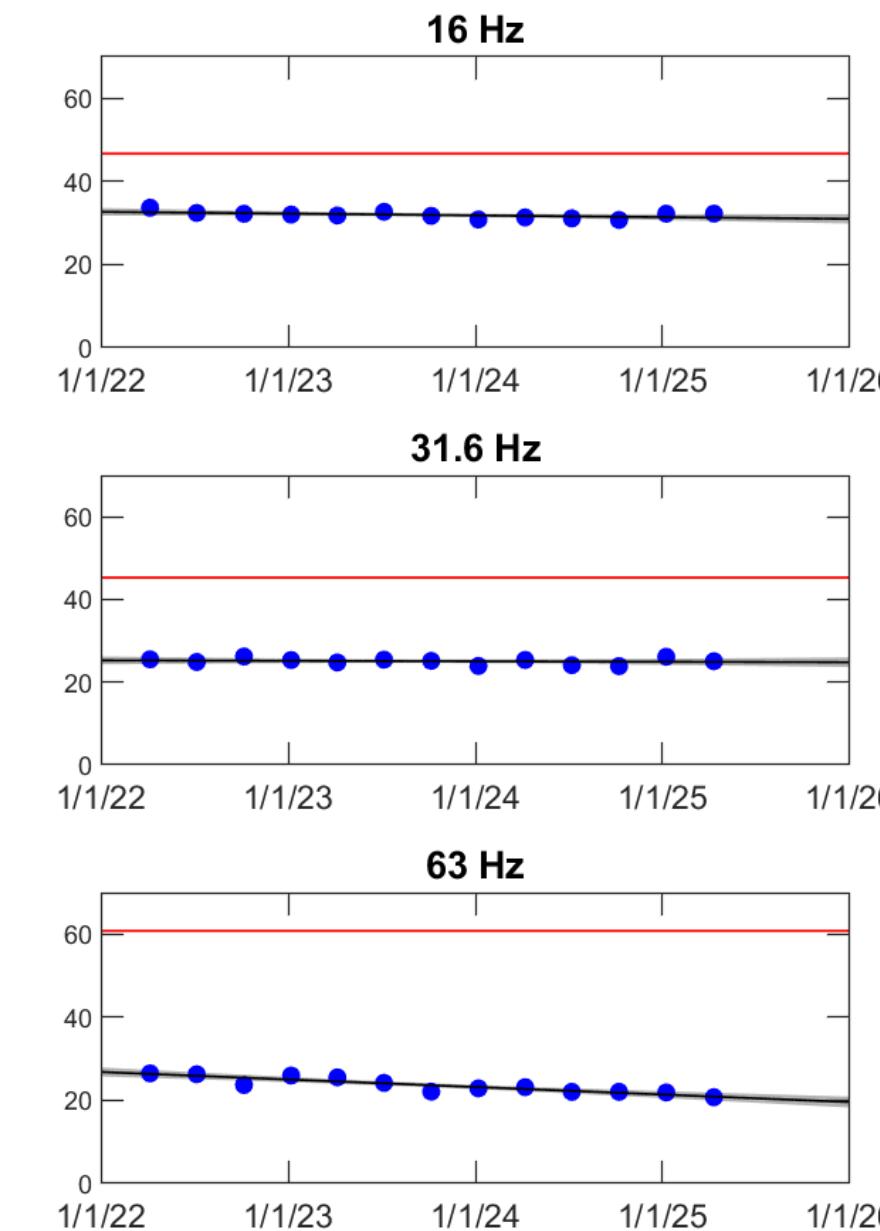


Example Trends



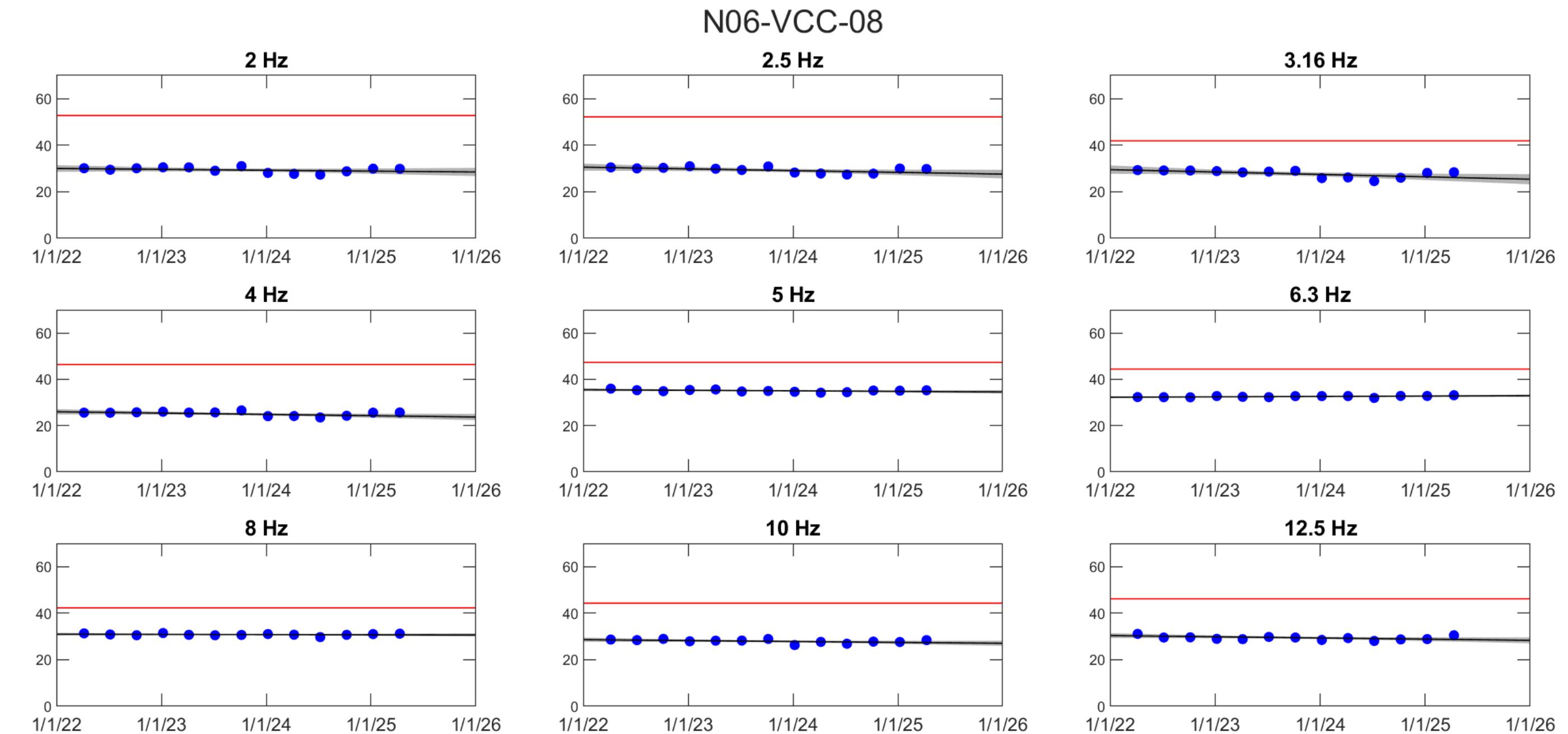


Example Trends



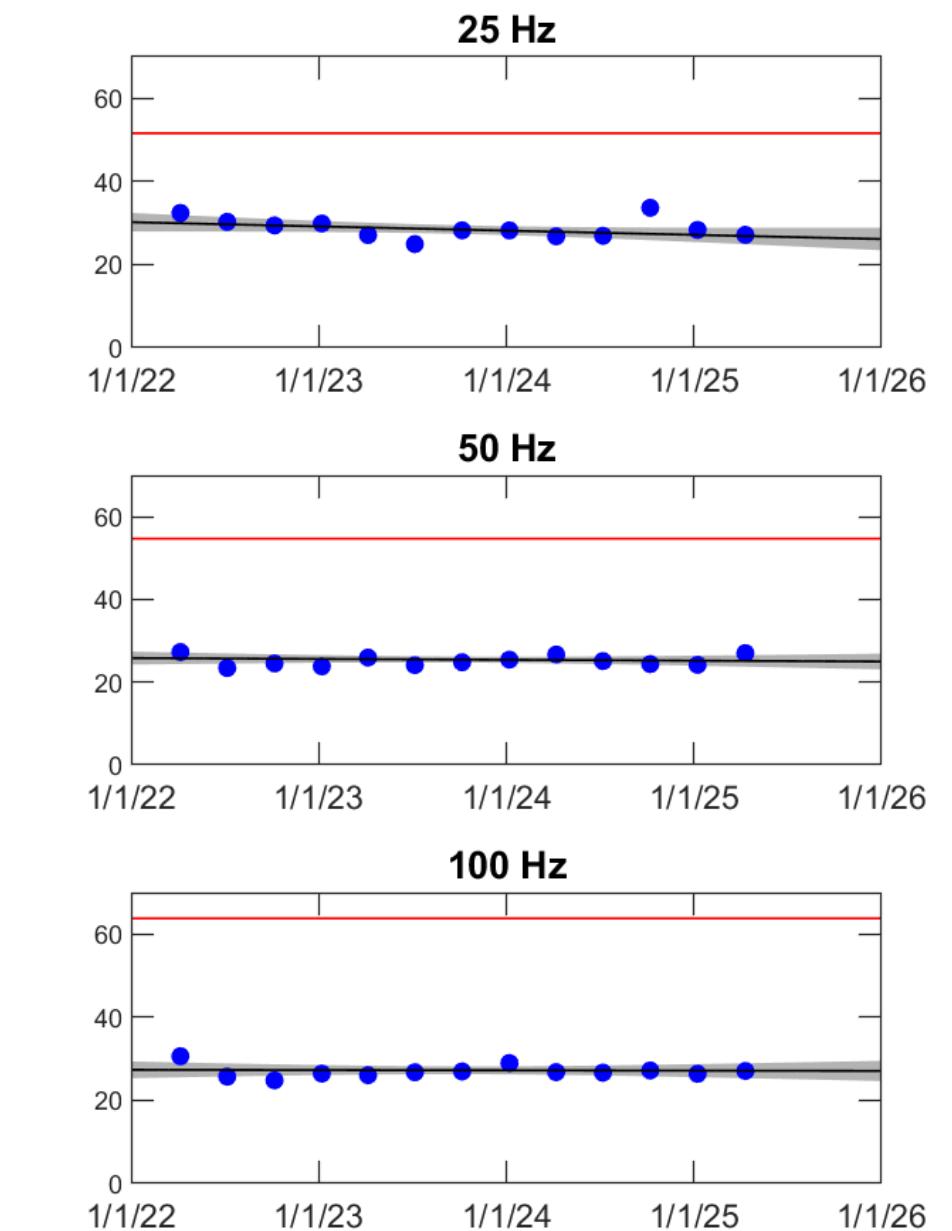
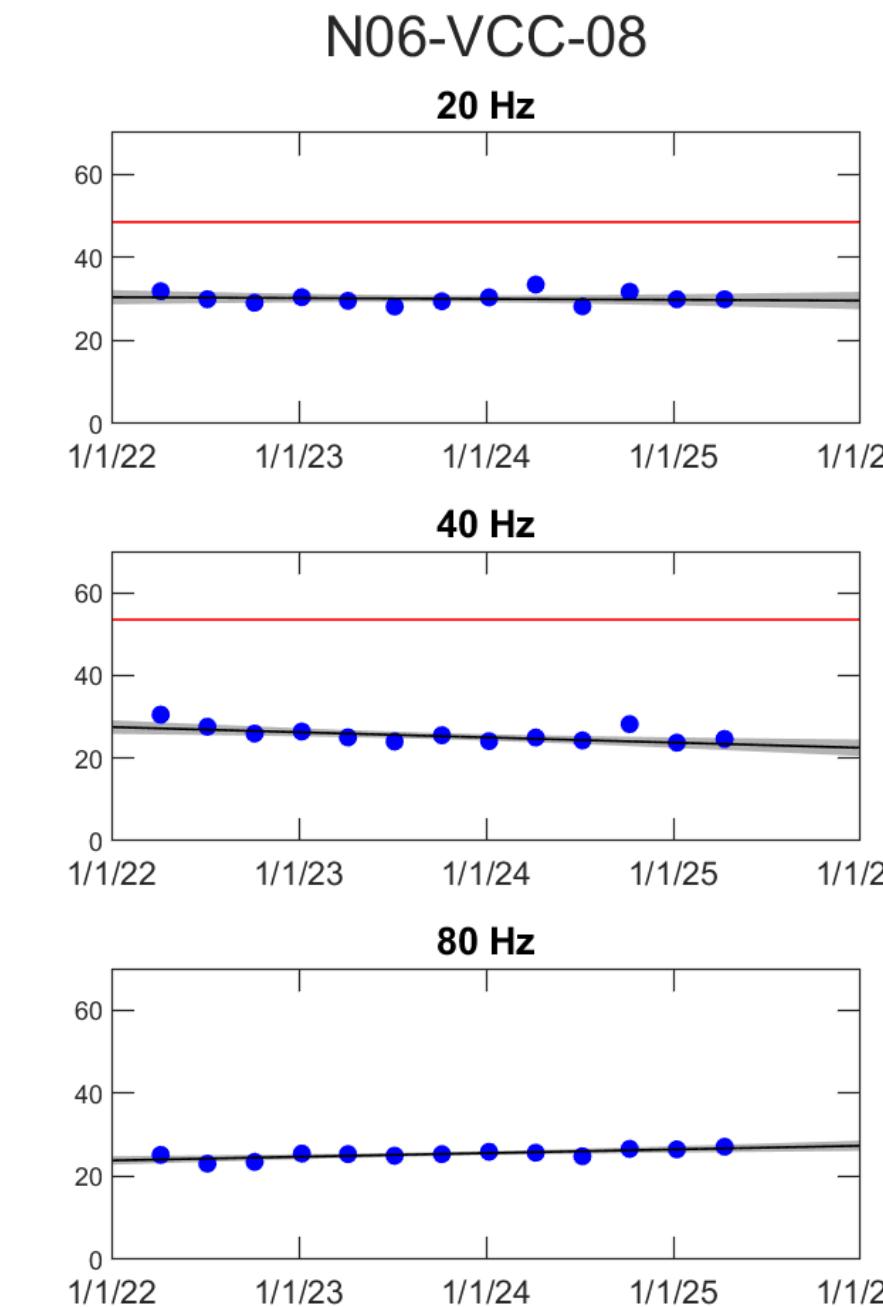
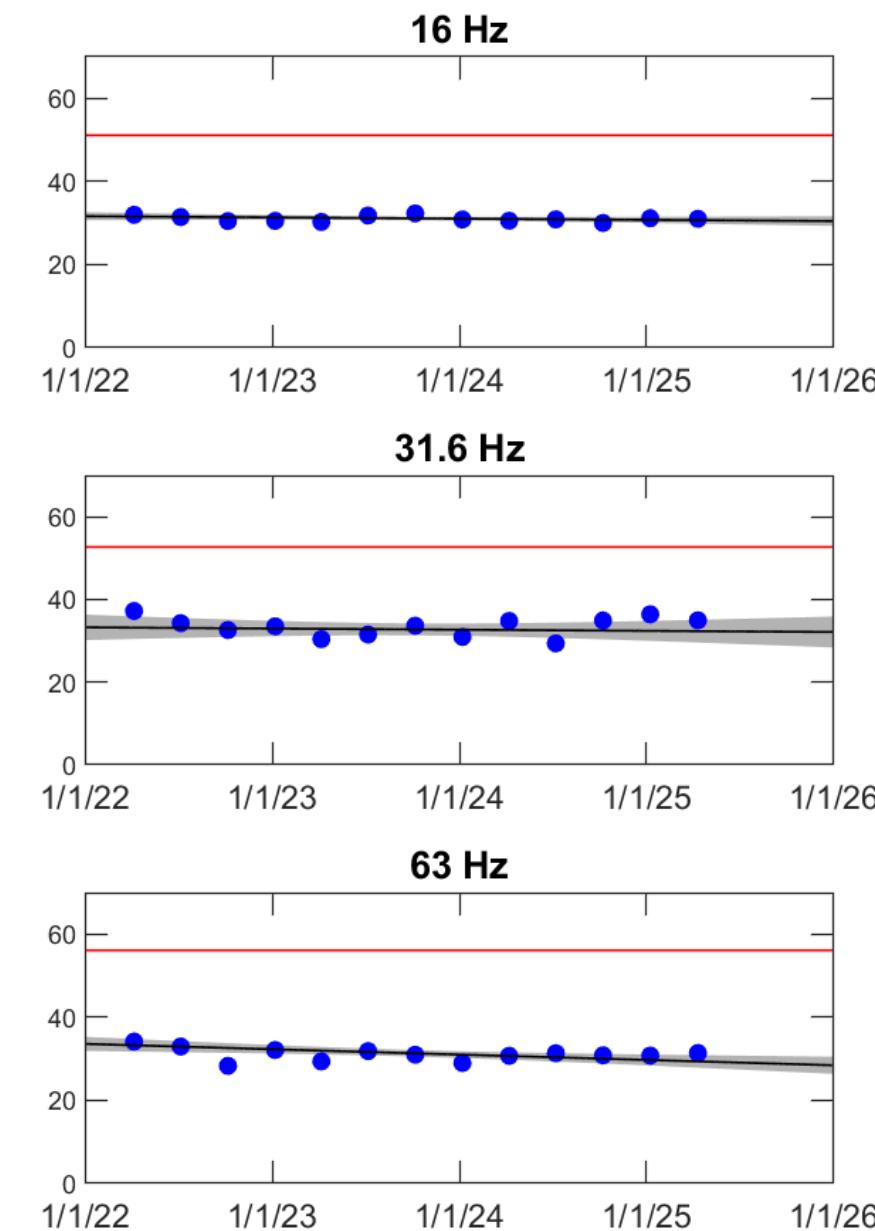


Example Trends



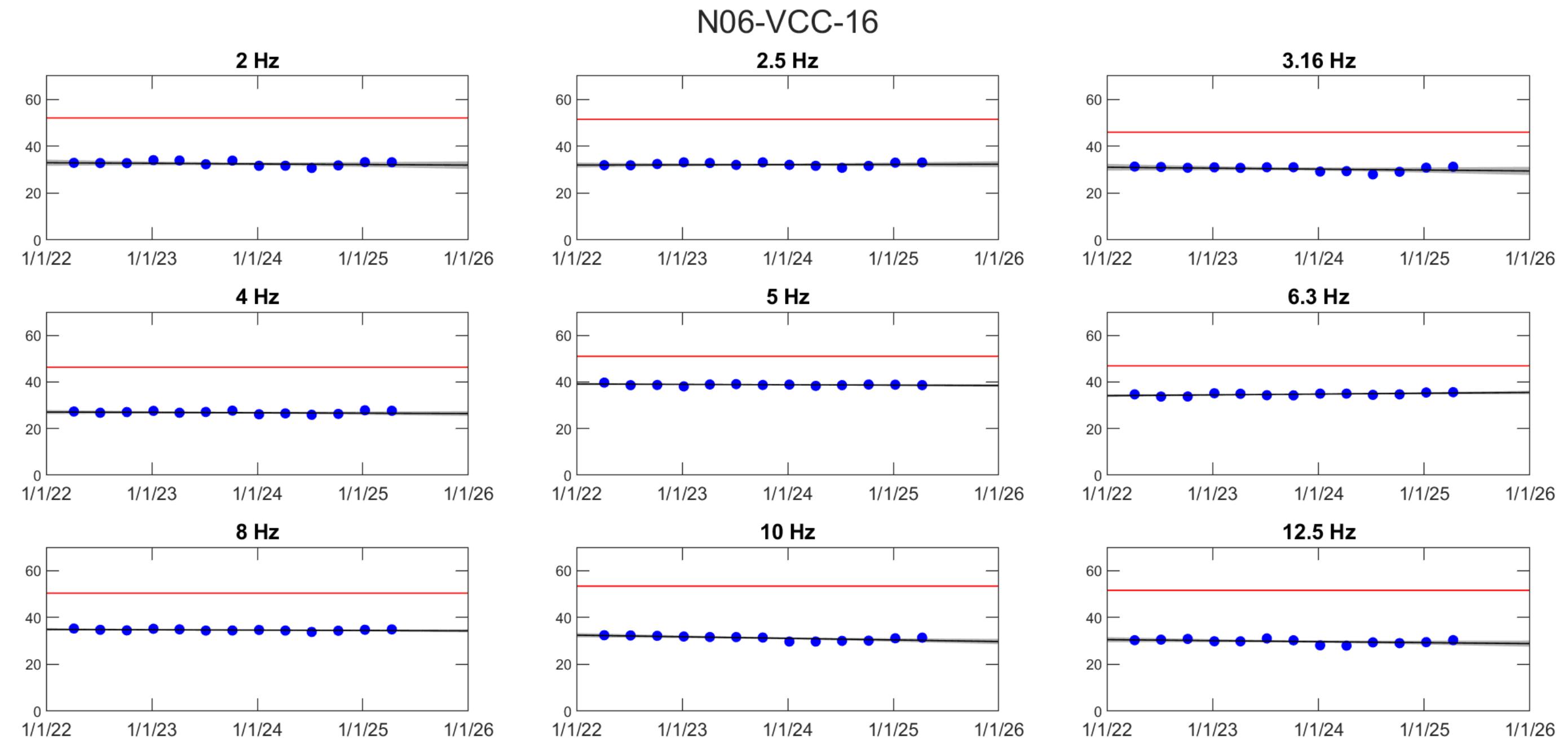


Example Trends



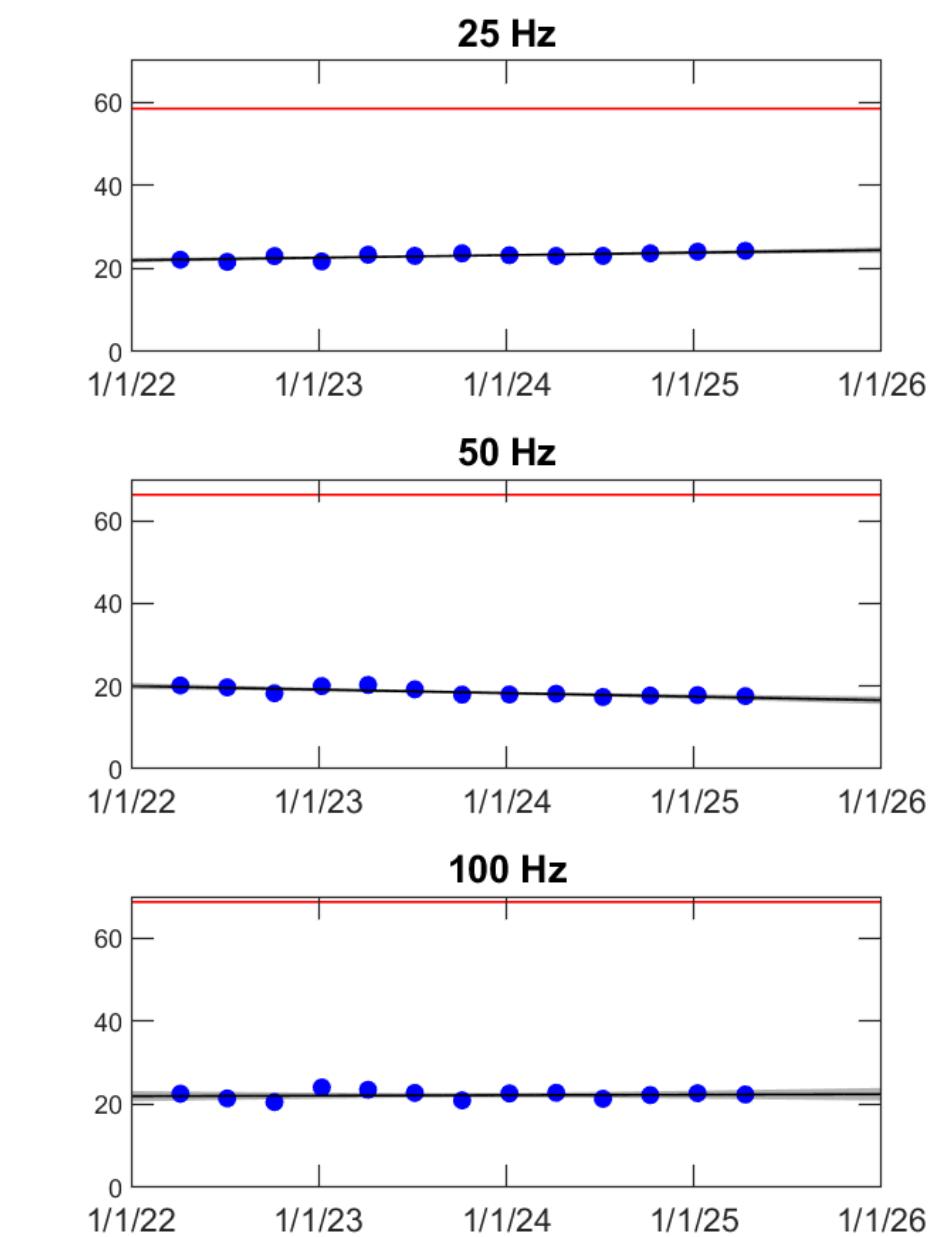
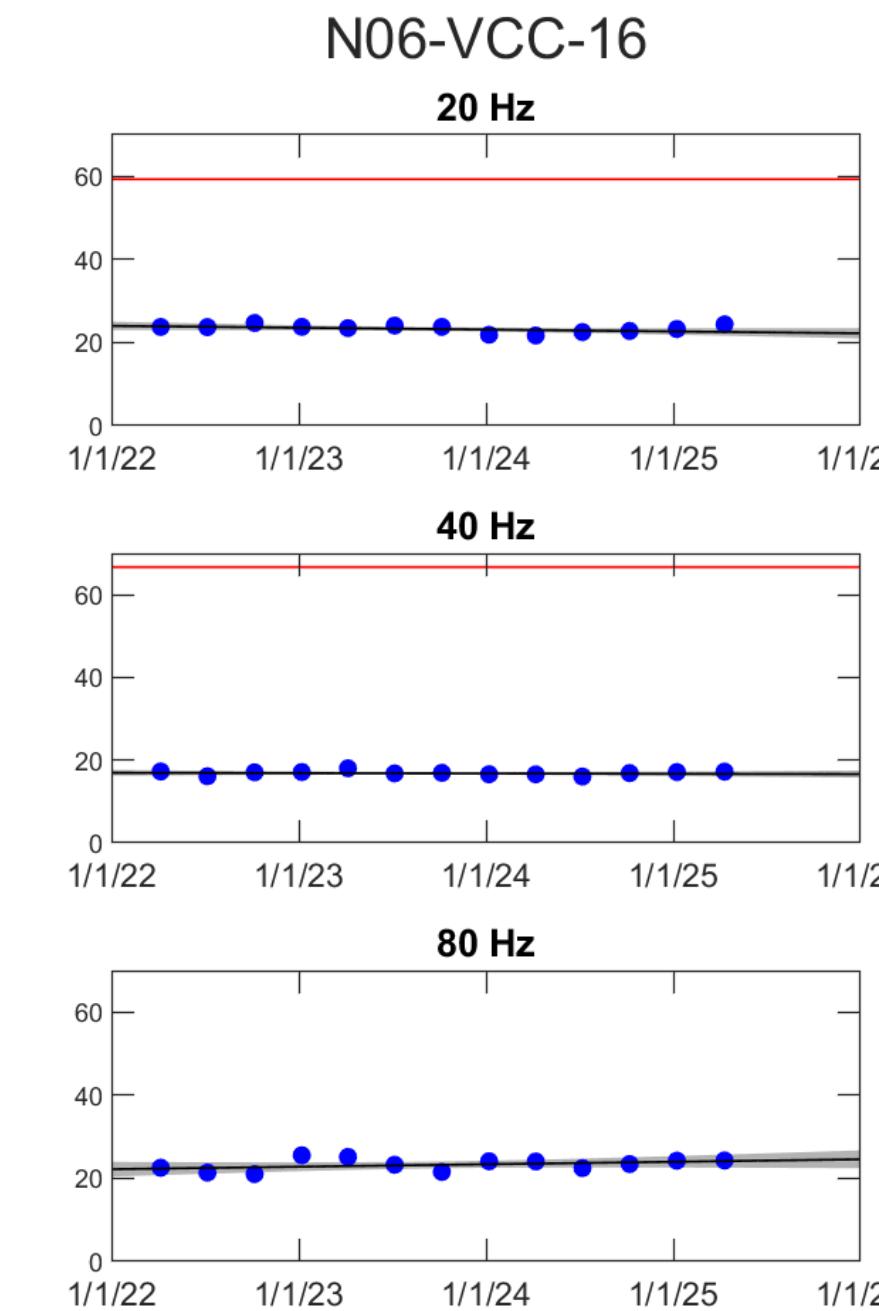
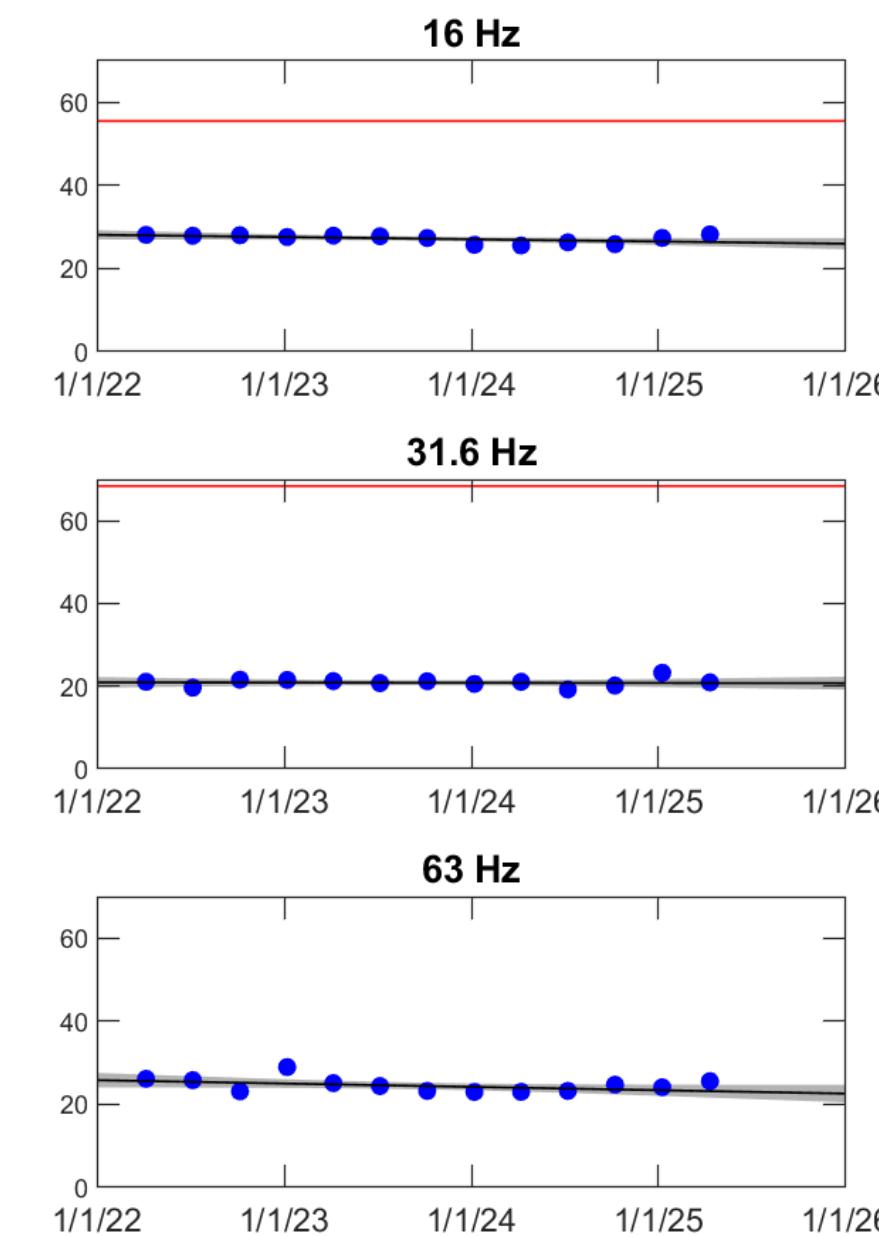


Example Trends





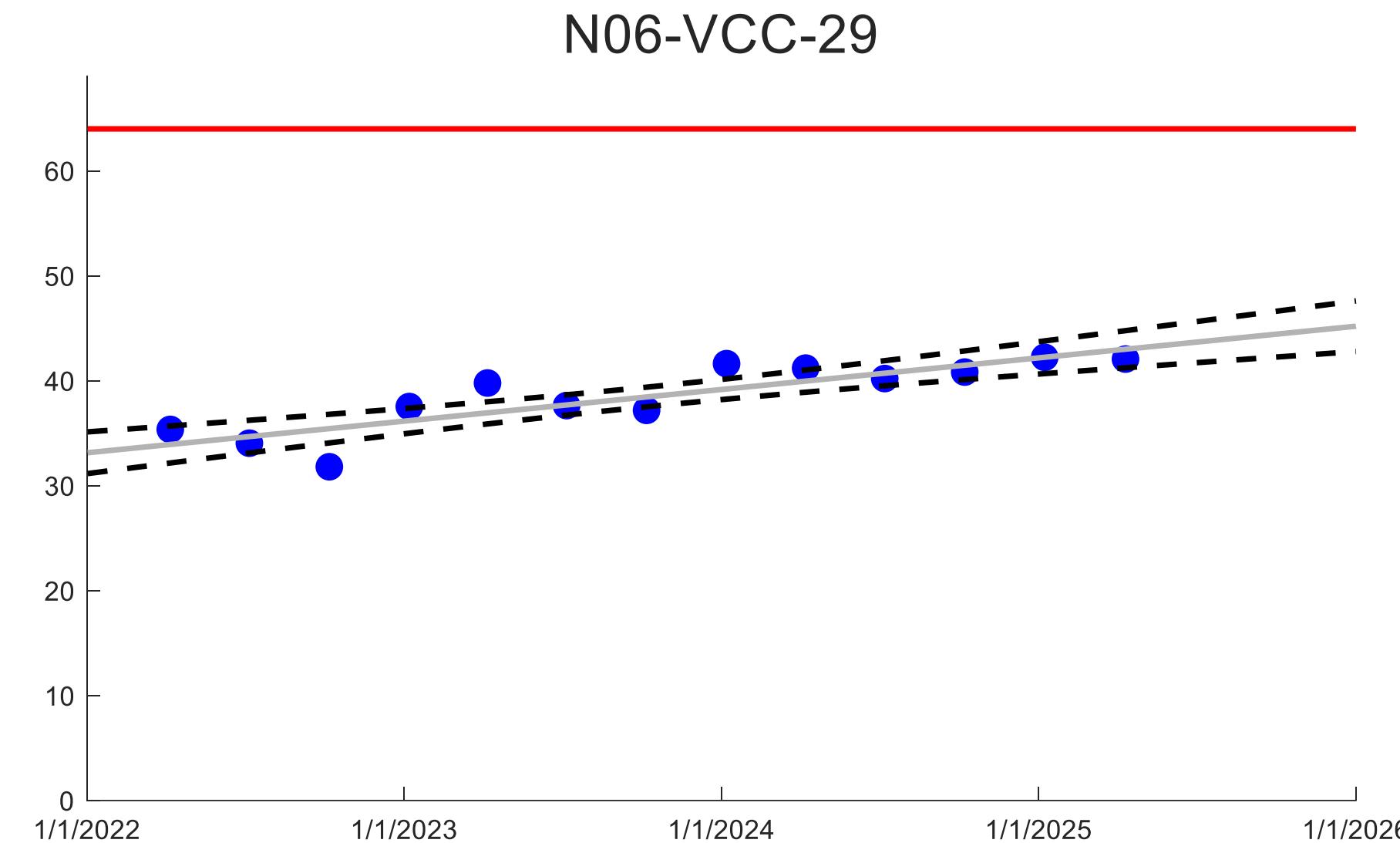
Example Trends





Example Trends – steepest trend

Monitor 29 (direct fixation, not on floating slab), 25 Hz





Maintenance and Operational Practices

- Grinding in 2023 did not noticeably alter vibration trends
- Wheel truing
- Operators slow down if WFD is triggered
- Turned off alerts for 2 Hz, 3.15 Hz, and 4 Hz 1/3-octave bands

Expected changes for various conditions

- Wheel flats
 - Increased vibration in 1/3-octave bands 40 Hz and above, especially for speeds below 30 mph
- Rail Corrugation
 - Increase in vibration in the band with speed/(corrugation wavelength)
- Lack of lubrication
 - Expect wheel squeal at frequencies well above 100 Hz. This system cuts off at 100 Hz and therefore would not detect squeal through vibration.



Future work

- Continue reporting trends to fulfill MIA requirements
- Data analysis beyond trending to identify broader patterns
- Opportunities for machine learning algorithms





Acknowledgements

- Sound Transit
- James T Nelson, PhD
- IEM (International Electronic Machines Corp)



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