2025 Annual Seminar & Trade Show

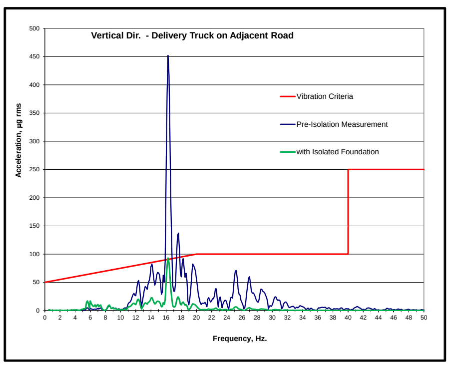
Vibration and Control of Building Structures

Over the years, vibration serviceability has been a high-profile issue on projects like the Millennium Bridge in England and several stadium grandstands in Europe. There are many less known vibration problems on office floors, monumental staircases and in manufacturing facilities throughout the U.S. Locally in Minnesota, many MNSEA members have noticed footfall vibration on floors at the Mall of America, and there was a wind-induced vibration failure of the Martin Olav Sabo Suspension Bridge (Midtown Greenway). This observed performance failures and MNSEA's strategic goal to advance technical knowledge are the motivation for this year's seminar topic.

SESSION 1: Vibration Engineering and Active Vibration Control of Floors
Paul Reynolds, PhD: CEO of CALMFLOOR, Honorary Professor at University of Exeter, UK

Innovative technologies for controlling building floor vibrations provide significant advantages over traditional methods throughout a building's lifecycle. Modern floor designs often prioritize vibration serviceability, and advanced vibration control solutions can reduce both construction costs and the carbon footprint of new buildings. For existing buildings, these technologies offer a cost-effective and non-disruptive way to resolve vibration issues without requiring extensive structural modifications. They also enable upgrades to accommodate more sensitive uses, such as converting office or commercial spaces into laboratories, healthcare facilities, or residential properties. This presentation offers a concise introduction to vibration engineering in buildings, focusing on the concept of active mass damping and its practical application to building floors. Several global case studies illustrate the successful deployment of this technology.

SESSION 2 – Vibration Serviceability and Measurements: Discussion, Demonstration, Case Studies.
Anthony J. Baxter, P.E., Principal at ESI Engineering
Peter G. Olney, P.E., Consulting Engineer at ESI Engineering



Vibration serviceability refers to the ability of a structure to function as intended without causing annoyance to its occupants or compromising the performance of sensitive equipment. It is an important design issue for buildings where human comfort is a priority, such as office buildings, hospitals, and residential structures. It is critical for buildings with sensitive laboratories, operating rooms, and equipment, such as high magnification microscopes, MRIs, and microelectronic fabrication tools. Understanding the vibration requirements is part of the challenge. Analysis during design and measurements of vibration levels can also be challenging. In this presentation, we will discuss the breadth of vibration serviceability, considerations for the structural engineer, measurements, and several project examples.

SESSION 3 – Introduction to passive TMDs, base isolation of structures & industrial equipment.
Florian Sassmannshausen – Vice President, Building Acoustics at GERB Vibration Control Systems

Tuned Mass Dampers (TMDs) and vibration isolators, though often hidden from view, play a crucial role in the performance of buildings and structures, impacting human comfort, acoustic comfort, or protecting vibration-sensitive equipment. Tuned mass dampers are essential for minimizing motion in tall and slender buildings, towers, long-span bridges, monumental staircases, and floors. Vibration isolators, on the other hand, protect vibration- or noise-sensitive spaces by reducing vibration transmission within mixed-use buildings, shield buildings from rail-induced vibration, or protect foundations and adjacencies from extreme vibrations from industrial equipment.
Established in 1908, GERB stands at the forefront of vibration control technology, offering tailored solutions for architectural, structural, and heavy industrial applications. This session will explore common challenges posed by vibrations in structures and delve into advanced engineering solutions that empower structural engineers in performance-based design, ensuring human comfort in buildings and structures.

MNSEA

Minnesota Structural Engineers Association

SEMINAR AND TRADE SHOW – MAY 13, 2025

Paul Reynolds, PhD: CEO of CALMFLOOR, Honorary Professor at University of Exeter, UK

Paul Reynolds is the CEO of CALMFLOOR, a company dedicated to commercializing innovative Active Mass Damping (AMD) technology for controlling vibrations in building floors. Prior to this, he spent over 15 years as an academic at the Universities of Sheffield and Exeter, where he led pioneering research in vibration control and serviceability and published over 150 papers in this field. Paul has also been a trusted consultant to the industry, contributing to dynamic testing and monitoring projects, including several UK sports stadiums, and providing solutions for high-profile challenges such as the London Millennium Bridge vibration issue. He currently holds an Honorary Professorship at the University of Exeter.

Anthony J. Baxter, P.E. – Principal at ESI Engineering

Tony Baxter has been principal at ESI Engineering since 2012. He has 36 years of experience, with 25 of those years at ESI, specializing in building and equipment vibration and noise control. Sensitive hospitals, labratories and microelectronics facilities are his speciality, including requirements for structural design. He has used modal analysis and other techniques to solve critical vibration related issues. His experience in vibration and noise analysis includes mechanical equipment vibration isolation, HVAC noise control, isolation system design, development of unique solutions, and troubleshooting. Tony has a passion for finding simple solutions to complex problems. He has published papers on Tuned Mass Dampers to control vibration in buildings and on predicting ground vibration from equipment foundations. Tony has a B.S. degree in Mechanical Engineering from Iowa State.

Peter G. Olney, P.E. – Consulting Engineer at ESI Engineering

Peter Olney joined ESI in the Summer of 2021 and serves as a Consulting Engineer in Structural Dynamics and Design. Peter holds a B.S. degree in Civil Engineering from the Illinois Institute of Technology in Chicago, IL. He has a M.S. degree in Natural Hazards and Risks in Structural Engineering from the Bauhaus-Universität Weimar in Germany where he also was a research associate for GRK 1462: Evaluation of Coupled Numerical and Experimental Partial Models in Structural Engineering. As part of the research group, Peter presented conference papers around the world related to the design of monitoring systems for structures. Peter has experience with vibration measurement systems, as well as design of building and industrial structures. He is a licensed civil engineer in Minnesota and Oregon.

Florian Sassmannshausen – Vice President, Building Acoustics at GERB Vibration Control Systems, Inc.

Florian is the Vice President at GERB Vibration Control Systems and specializes in building vibration and acoustics. With 15 years of experience, he has successfully overseen the design and implementation of vibration mitigation solutions across a broad spectrum of global projects. Florian's expertise allows him to approach complex, technically demanding challenges with innovative, out-of-the-box thinking. Typical projects encompass building base vibration isolation, floating floors to protect vibration-sensitive areas, noise mitigation in mixed-use developments, discrete isolation of beams and columns, and the retrofitting of existing structures, rooftop helipads, and buildings.

"It's all springs and dampers," – but with the unique challenge to balance structural integrity with minimal displacement, while delivering exceptional isolation performance through elasticity – two seemingly opposing objectives. Collaborating with a talented team of structural, civil, and mechanical engineers at GERB, Florian helps drive forward the company's legacy. Founded in 1908 in Berlin, GERB is a world-renowned leader in vibration isolation and vibration control engineering and manufacturing.

MINNESOTA STRUCTURAL ENGINEERS ASSOCIATION

2025 Annual Seminar & Trade Show

Vibration Serviceability & Measurements
Discussion, Demonstration, Case Studies

May 13, 2025

Anthony J. Baxter, PE (MN)
Peter G. Olney, PE (MN, OR)

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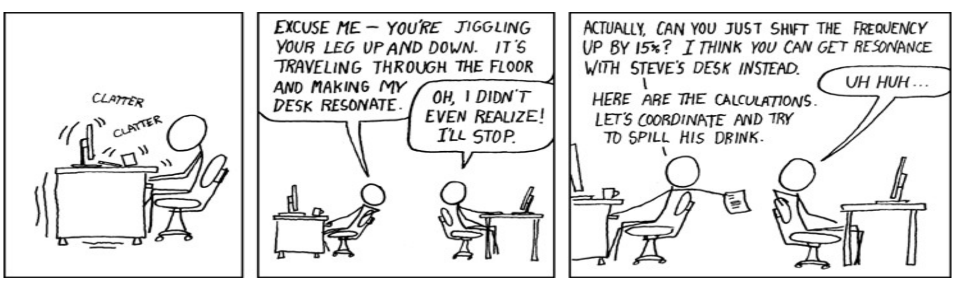

https://xkcd.com/228

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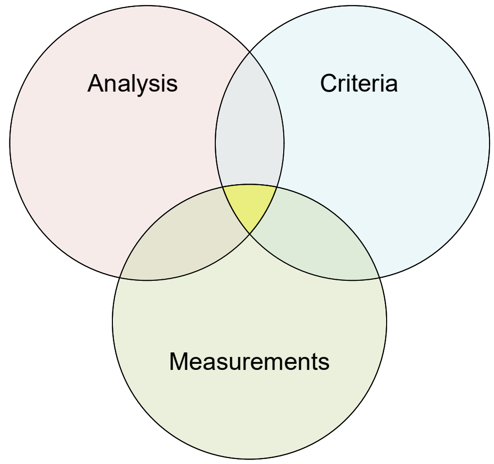
Vibration Serviceability & Measurements

Discussion, Demonstration, Case Studies

1. ESI’s history and what we do
2. Vibration Serviceability
3. Criteria
4. Measurements Demo
5. Case Studies



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ESI’s History

- Minnesota based consulting engineering firm since 1970
- Provide specialized engineering services
- Services have changed over time
- Specialists in vibration and noise control

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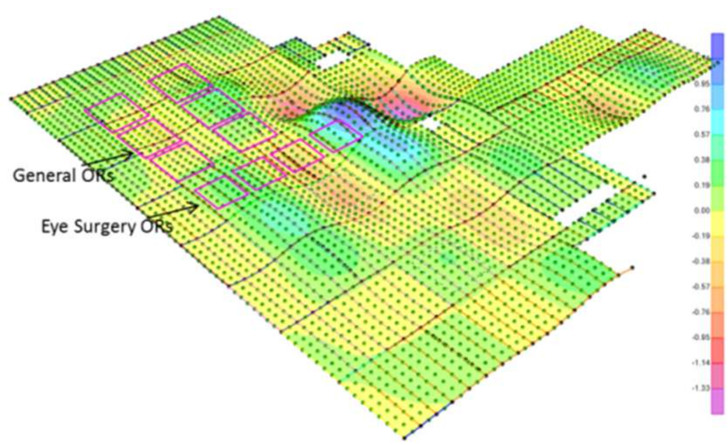
Supporting Innovative Design

Vibration Analysis for Healthcare, Manufacturing and Research

Supporting Innovative Design

FEA and Dynamic Analysis

- Structures
- Foundations
- Equipment
- Isolation



Supporting Innovative Design

Vibration Measurements and Monitoring

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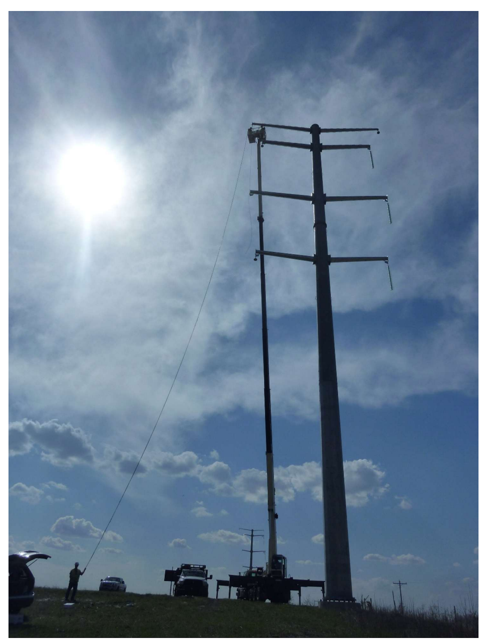
Supporting Innovative Design

Vibration Measurements and Monitoring



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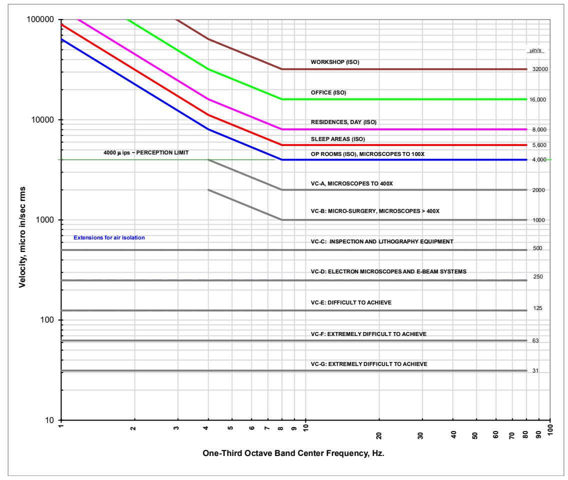
Vibration Serviceability

The ability of a structure to perform its intended function without vibration that causes distraction, discomfort, or process and quality issues.

- Industrial facility
- Office building
- Operating room
- Wafer fab

Usability, Comfort, and Operational Performance.



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Vibration Serviceability

Vibration is a critical issue in environments with sensitive equipment, processes and activities.

- **Distraction** – vibration of microscope images during surgery – stress
- Discomfort – office floor vibration from walking
- Process issues – cell growth rings
- Quality issues – poor MRI images, wafer lithography line width variability

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Vibration Serviceability

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Vibration Serviceability

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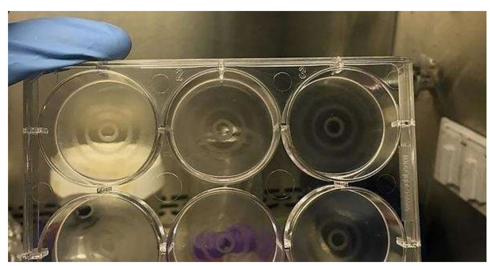

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Vibration Serviceability

Vibration is a critical issue in environments with sensitive equipment, processes and activities.

- Distraction – vibration of microscope images during surgery – stress
- Discomfort – office floor vibration from walking
- Process issues – cell growth rings
- **Quality issues** – poor MRI images, wafer lithography line width variability

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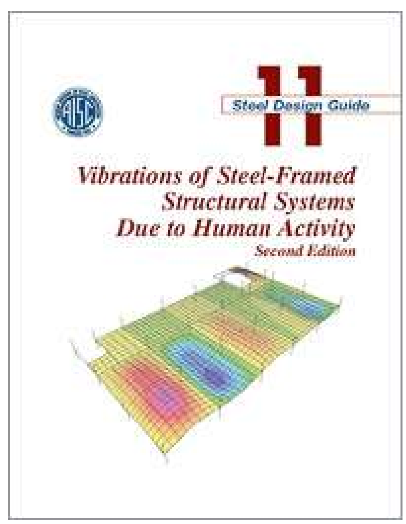
Vibration Serviceability

Three basic questions need to be answered:

- Who or what will be affected by vibration?
- What is the source of the vibration?
- What criteria will be used to evaluate the vibration?

ESI can help!



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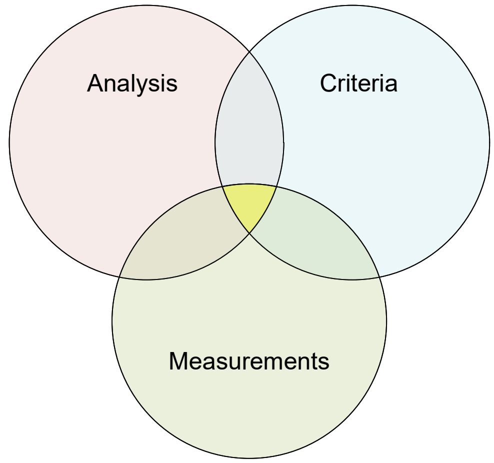
Vibration Serviceability

- **Predicting the Dynamic Response**
  - Steel
  - Concrete
  - Wood
  - Foundation (in soil or isolated)
- Determining the Vibration Requirements
  - Human Comfort
  - Sensitive Equipment & Processes
- Measurements
  - Existing Conditions
  - Final Results



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Vibration Criteria

What do these values have in common? Which is the highest and which is the lowest?

0.50	%g
0.98	mils pk-pk
3535	µg rms
21739	µips rms
1.37	in/sec^2 rms
86.7	VdB
0.031	in/sec PPV

What is VdB???

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Vibration Criteria Are Confusing!

- Many different ways to describe vibration amplitude
  - Displacement, velocity, acceleration
  - 0-pk, pk-pk, rms
  - %g, PPV, VdB
- Time or frequency domain?
- Depends on the receiver
  - people, process, equipment, building damage
- Depends on the characteristics
  - steady state, transient, random

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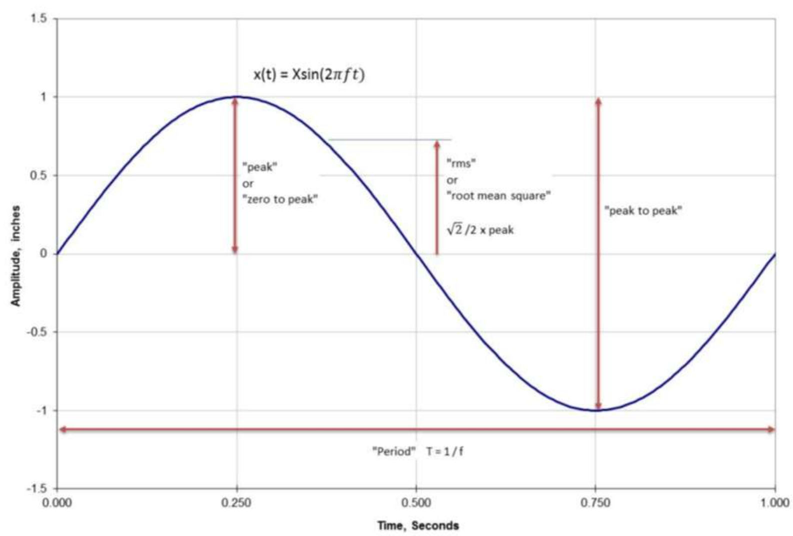
Sinusoidal Motion / Vibration

Time Domain



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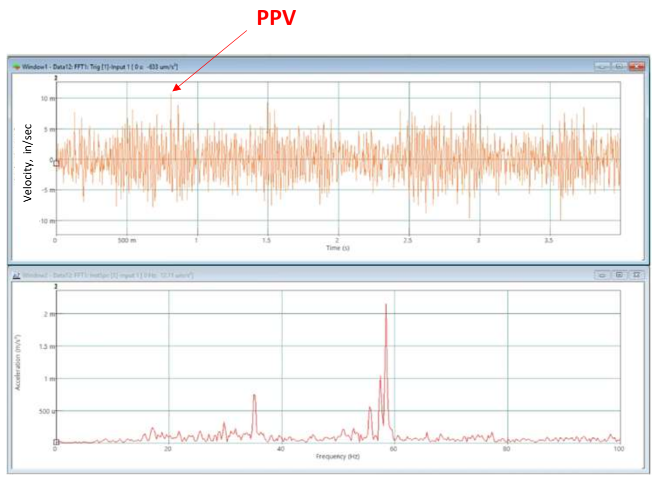
Time Domain

PPV - Peak Particle Velocity

- highest amplitude in the time series
- building damage from construction
- the advantage is that it is simple



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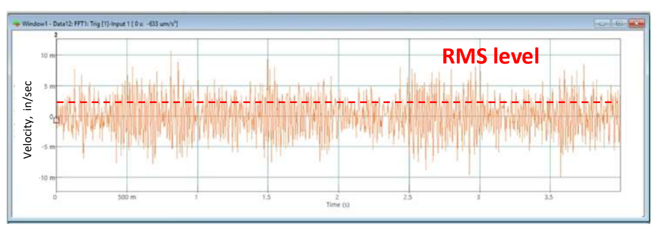
Time Domain

RMS - Root Mean Square Amplitude

- statistical measure of the magnitude
- common value in time domain analysis
- a way to quantify the "overall" levels
- useful for comparing different data sets



$$V_{rms} := \sqrt{\frac{1}{T} \cdot \int_0^T V(t)^2 \, dt}$$

$$RMS = \sqrt{\frac{1}{n} \sum_i x_i^2}$$

RMS = root mean square
n = number of measurements
x_i = each value

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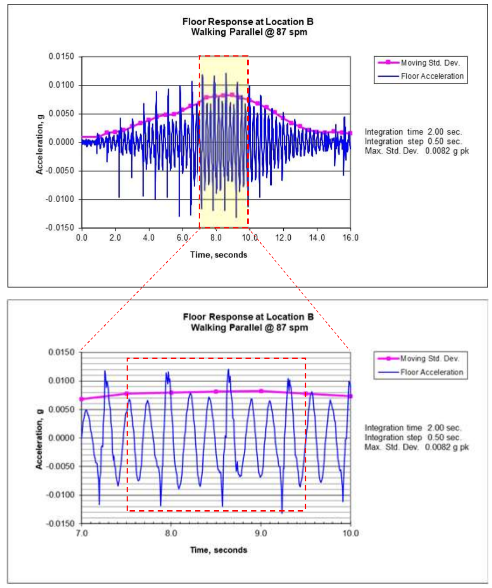
Footfall – %g Criterion from DG11

%g criterion – 0.5%

- time domain criterion
- moving RMS integrated over 1 to 2 sec
- scaled to 0-pk by multiplying by 1.414
- Equivalent Sinusoidal Peak Acceleration
- 18 Hz low pass filter is commonly used
- max amplitude is reported

$$g_{rms} := \sqrt{\frac{1}{(t_2 - t_1)} \cdot \sum_{t = t_1}^{t_2} a(t)^2}$$

$$g_{pk} := \frac{2}{\sqrt{2}} \cdot g_{rms}$$



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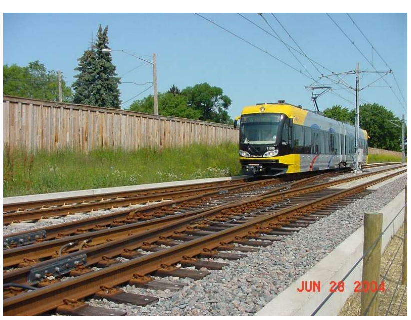
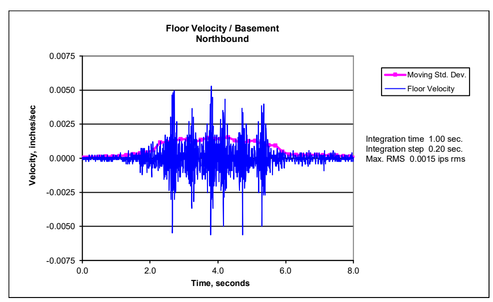
VdB – Requirement on LRT Projects

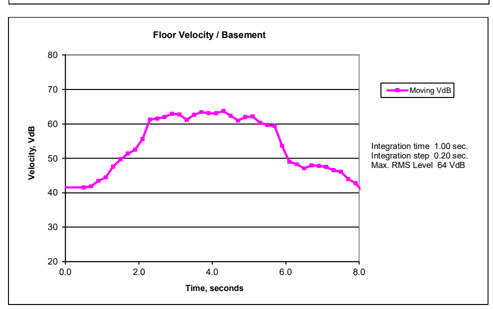
Velocity rms level

- time domain criterion
- moving RMS
- 1 sec integration time
- decibel level relative to 1 μ inch/sec rms



$$VdB := 20 \cdot \log\left(\frac{Vel}{1 \cdot \frac{\mu \cdot in}{sec} \cdot rms}\right)$$





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Vibration Criteria Are Confusing!

- Many different ways to describe vibration amplitude
  - Displacement, velocity, acceleration
  - 0-pk, pk-pk, rms
  - %g, PPV, VdB
- Time or frequency domain?
- Depends on the receiver
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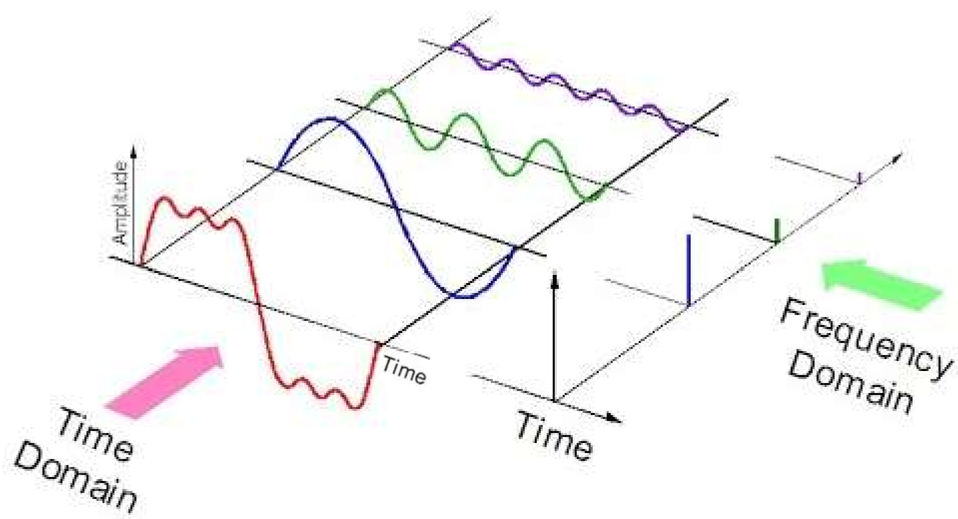

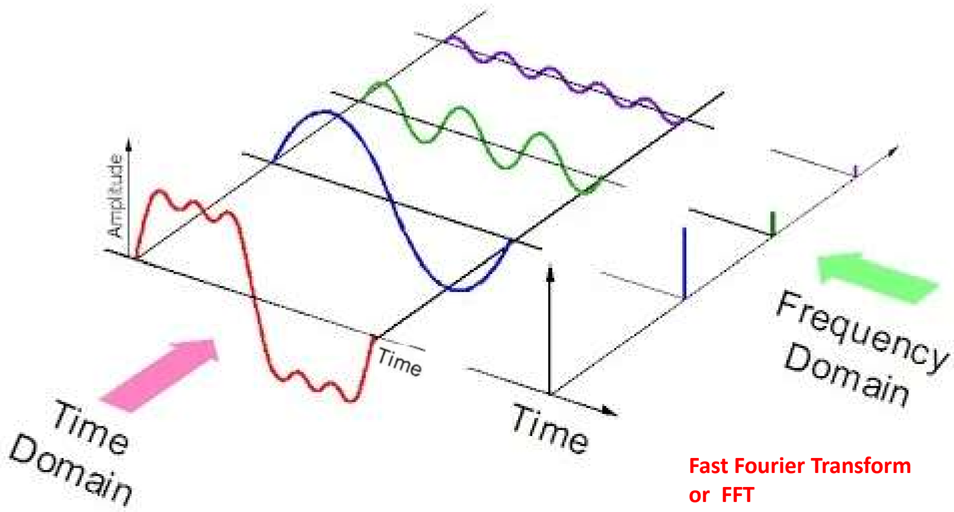

Fast Fourier Transform
or FFT

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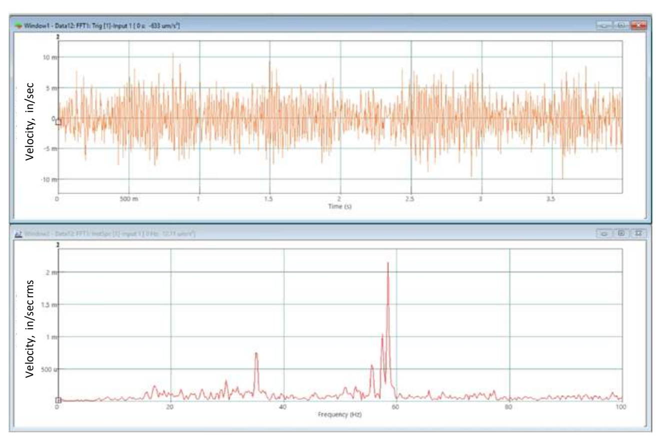
Signal Analysis

Time Domain

Frequency Domain
- FFT
- spectrum
- narrow band
- constant width



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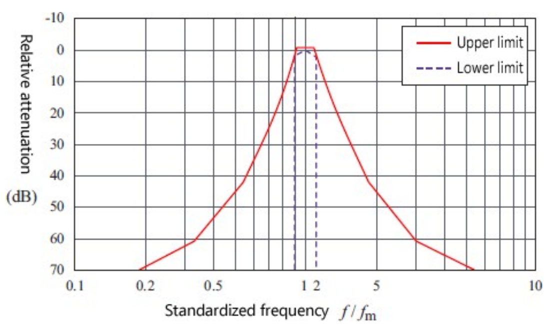
1/3 Octave Band Amplitudes

Proportional Bandwidth Filters



Band No.	Nominal Centre Frequency	Third-Octave Passband	Octave Passband
1	1,25 Hz	1,12 – 1,41 Hz	
2	1,6	1,41 – 1,78	
3	2	1,78 – 2,24	1,41 – 2,82 Hz
4	2,5	2,24 – 2,82	
5	3,15	2,82 – 3,55	
6	4	3,55 – 4,47	2,82 – 5,62
7	5	4,47 – 5,62	
8	6,3	5,62 – 7,08	
9	8	7,08 – 8,91	5,62 – 11,2
10	10	8,91 – 11,2	
11	12,5	11,2 – 14,1	
12	16	14,1 – 17,8	11,2 – 22,4
13	20	17,8 – 22,4	
14	25	22,4 – 28,2	
15	31,5	28,2 – 35,5	22,4 – 44,7
16	40	35,5 – 44,7	
17	50	44,7 – 56,2	
18	63	56,2 – 70,8	44,7 – 89,1
19	80	70,8 – 89,1	
20	100	89,1 – 112	
21	125	112 – 141	89,1 – 178
22	160	141 – 178	
23	200	178 – 224	
24	250	224 – 282	178 – 355
25	315	282 – 355	
26	400	355 – 447	
27	500	447 – 562	355 – 708
28	630	562 – 708	
29	800	708 – 891	
30	1000	891 – 1120	708 – 1410
31	1250	1120 – 1410	
32	1600	1410 – 1780	
33	2000	1780 – 2240	1410 – 2820
34	2500	2240 – 2820	
35	3150	2820 – 3550	
36	4000	3550 – 4470	2820 – 5620
37	5000	4470 – 5620	
38	6300	5620 – 7080	
39	8000	7080 – 8910	5620 – 11200
49	10K	8910 – 11200	
41	12,5K	11,2 – 14,1K	
42	16K	14,1 – 17,8K	11,2 – 22,4K
43	20K	17,8 – 22,4K	

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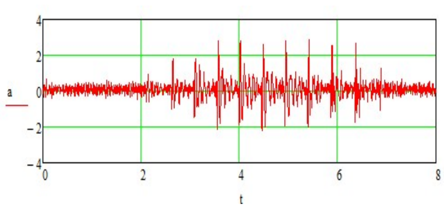
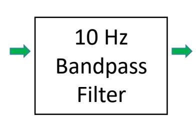
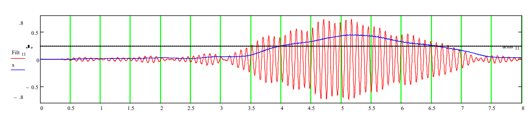
Example of 1/3 Octave Filtering

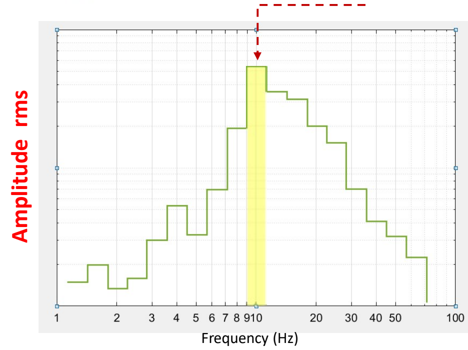
Footfall vibration





Output for the 10 Hz band (8.91 to 11.2 Hz)





(Don't try this at home)

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Criteria for Human Comfort

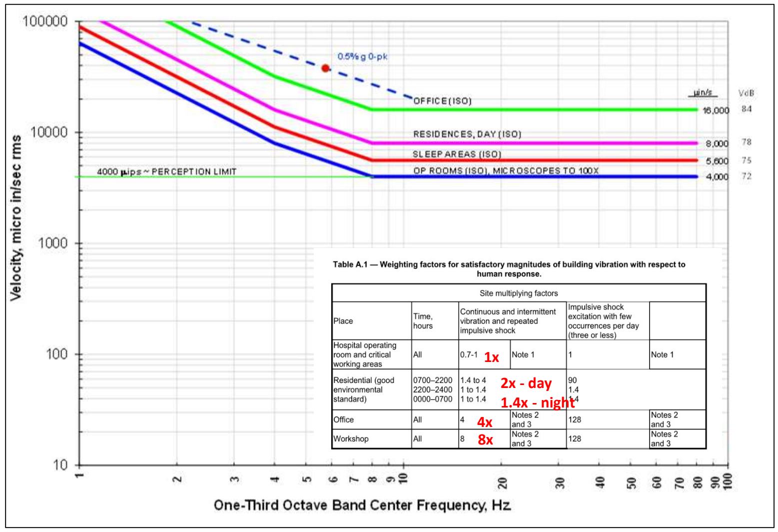

Table A.1 — Weighting factors for satisfactory magnitudes of building vibration with respect to human response.

Site multiplying factors					
Place	Time, hours	Continuous and intermittent vibration and repeated impulsive shock		Impulsive shock excitation with few occurrences per day (three or less)	
Hospital operating room and critical working areas	All	0.7-1 1x	Note 1	1	Note 1
Residential (good environmental standard)	0700–2200 2200–2400 0000–0700	1.4 to 4 1 to 1.4 1 to 1.4	2x - day 1.4x - night	90 1.4 1.4	
Office	All	4 4x	Notes 2 and 3	128	Notes 2 and 3
Workshop	All	8 8x	Notes 2 and 3	128	Notes 2 and 3

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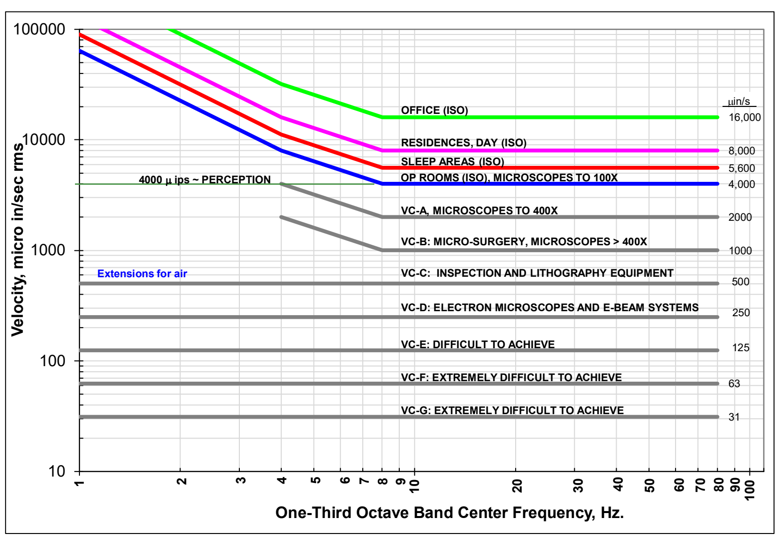
Criteria for Sensitive Equipment & Process



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Vibration Criteria

Need to ask questions about the criteria to understand what it represents.

Design Guide 11	0.50	%g
mil = 0.001"	0.98	mils pk-pk
Common acceleration spec	3535	µg rms
Common velocity requirement	21739	µips rms
Acceleration	1.37	in/sec^2 rms
Velocity decibel level	86.7	VdB
Peak particle velocity	0.031	in/sec PPV

They represent the same amount of motion!
(for a sinusoid at 10.0 Hz)

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Are Vibration Criteria Less Confusing Now?

Key Takeaways

- Many different ways to describe motion amplitude
- Time or frequency domain
- Depends on the receiver
  - people, process, equipment, building damage
- Depends on the characteristics
  - steady state, transient, random

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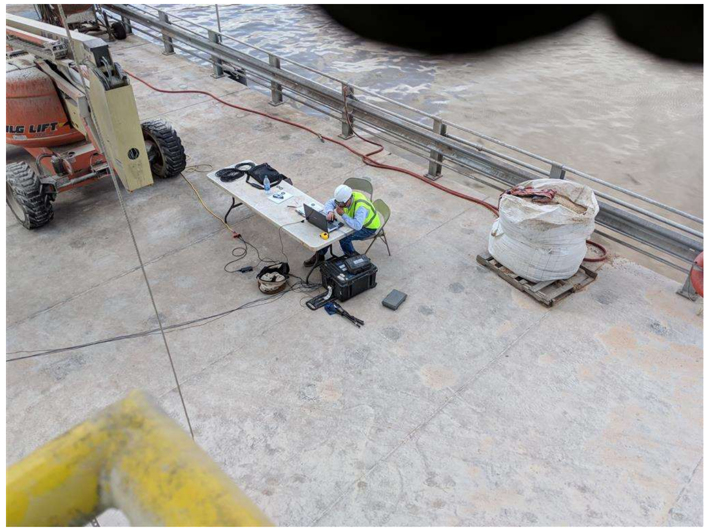
Measurement Demo



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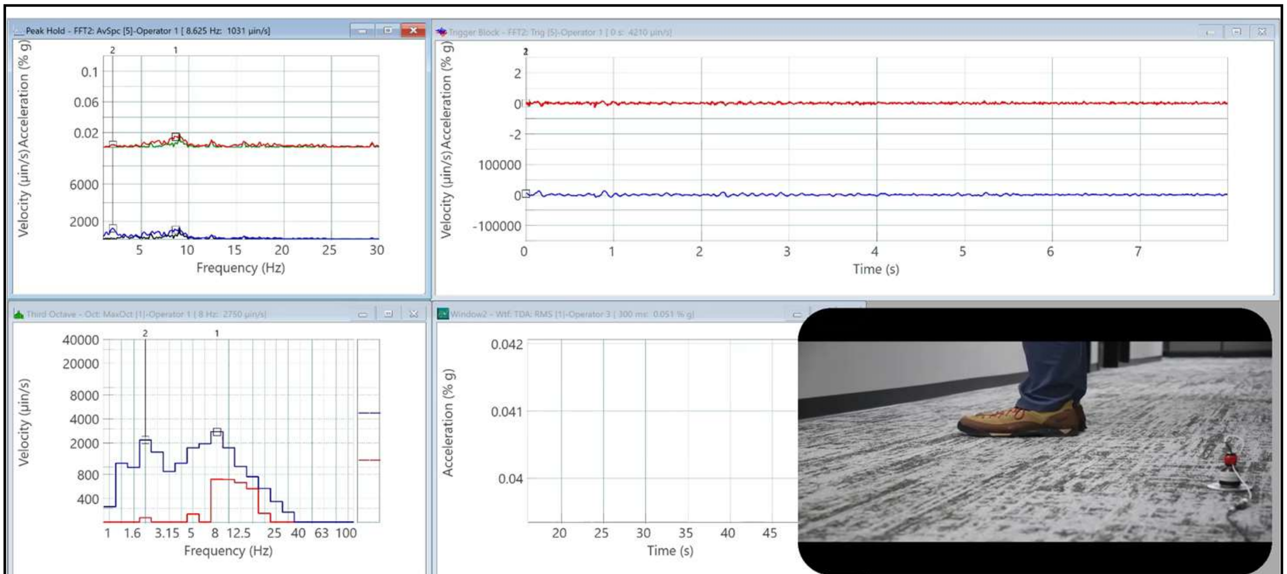

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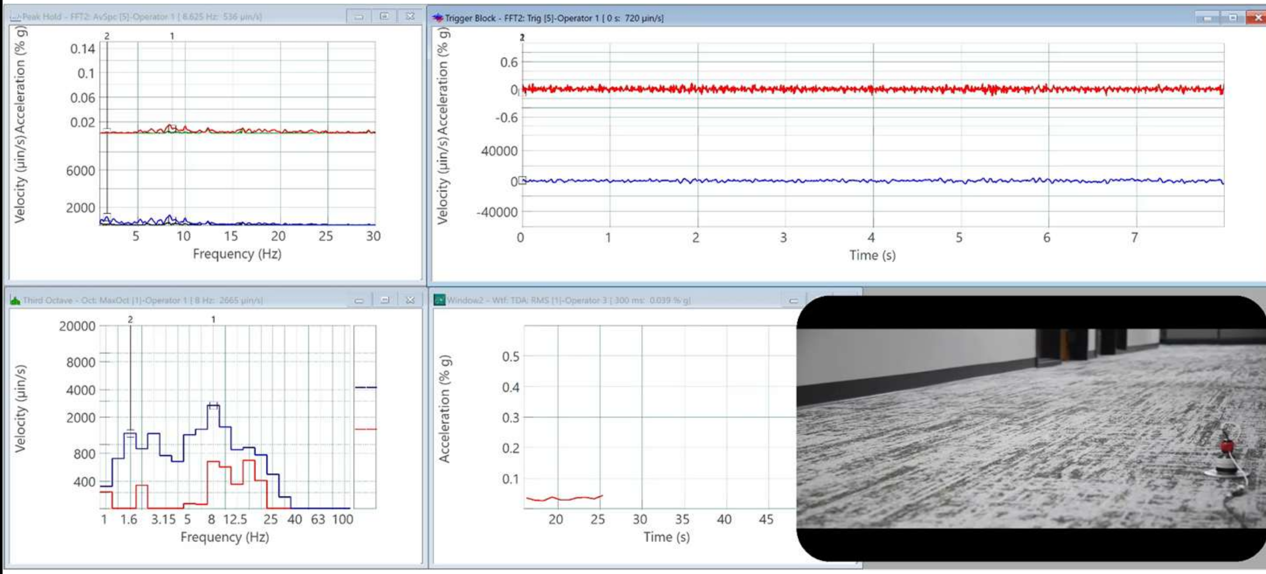

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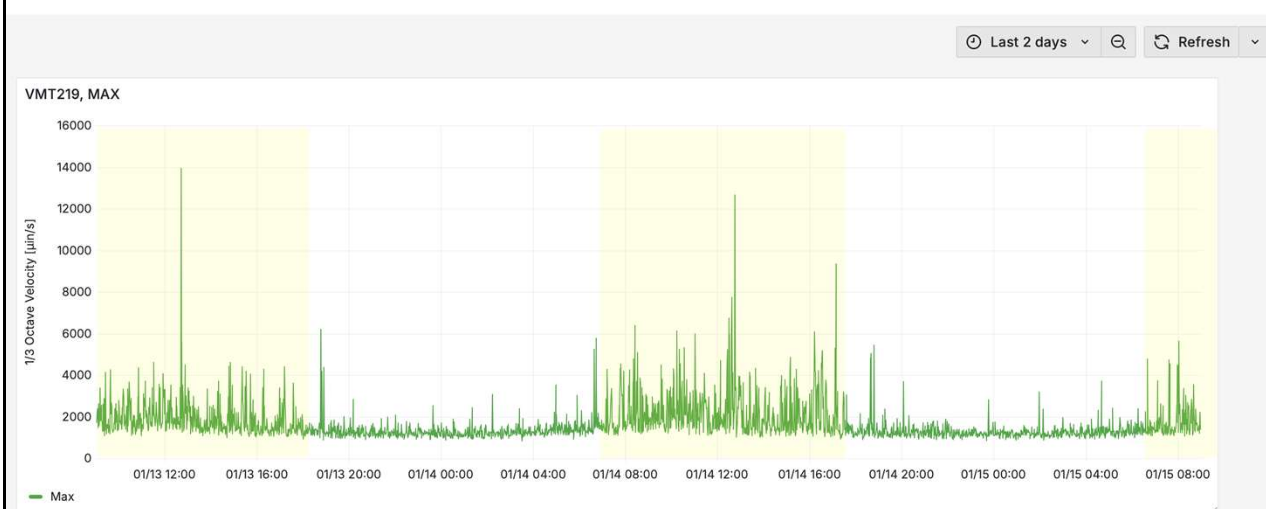
Office Vibration - Max 1/3 Octave Band Level



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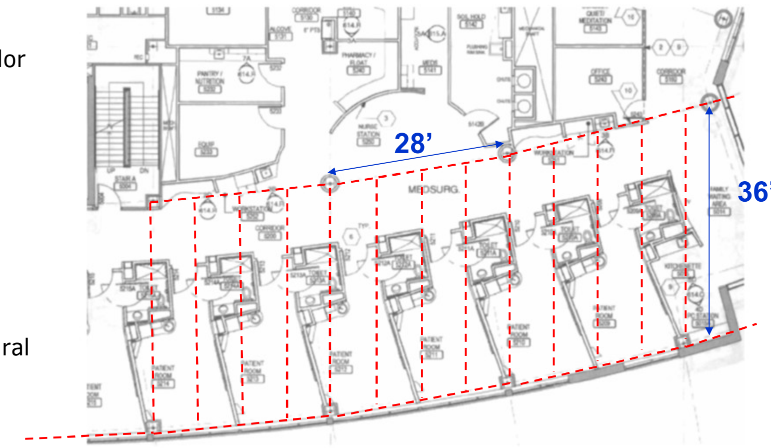
Example 1 – Floor Structure for Hospital Patient Rooms

- Patient rooms with the main corridor in the same bay.
- Composite steel, 28’ x 36’ bays.
- Design criterion – ISO Residential Night
- Walking speed to match the third harmonic of walking with floor frequency.
- Conclusion – the proposed structural framing was adequate.



Framing – W18x35 84” on center, 36 ft span, W24 girders

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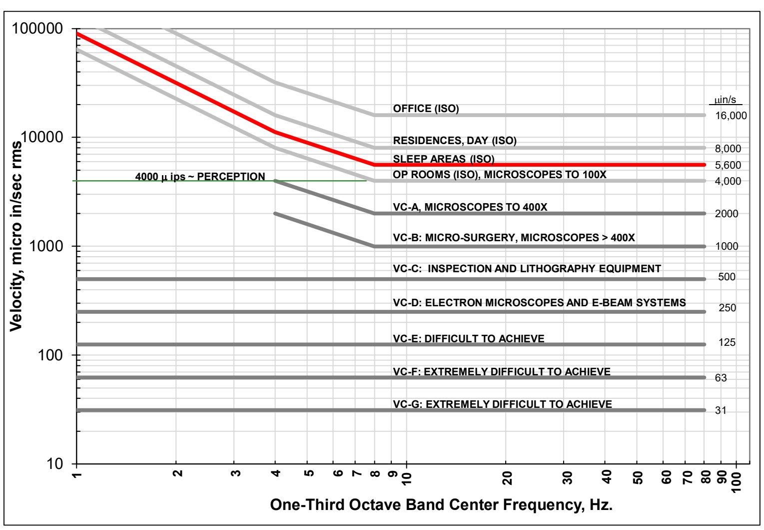
Example 1 – Floor Structure for Hospital Patient Rooms



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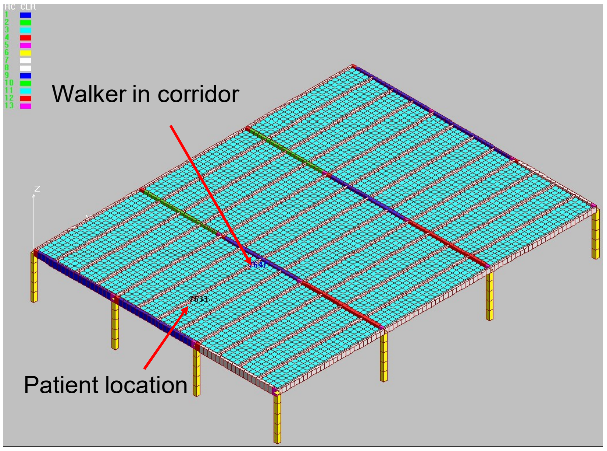
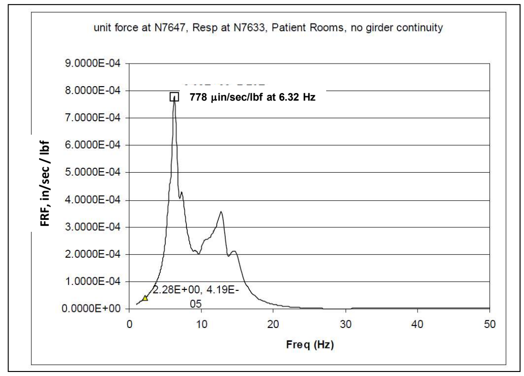
Finite Element Model and Harmonic Analysis



The Finite Element Model



Frequency Response Function (FRF) for velocity at the patient due to unit force at the walker.

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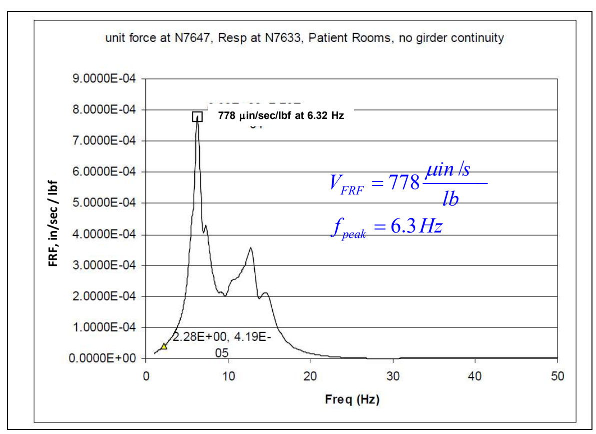
Applying Footfall Force from AISC DG 11 (1st Ed.)

$$\frac{a}{g} = \frac{R\,P\,0.83\,e^{-0.35 f_n}}{\beta\,W}$$ *equation 2.3*

$$\alpha_3 = 0.83\,e^{-0.35 f_n} = 0.091$$
$$P = 185\,lb$$
$$R = 0.75 \text{ (resonance buildup factor)}$$

$$V_{rms} = \frac{1}{\sqrt{2}}(R\,P\,\alpha_3)V_{FRF} = 6950\,\mu\text{in/sec rms}$$



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Vibration Measurements During Construction

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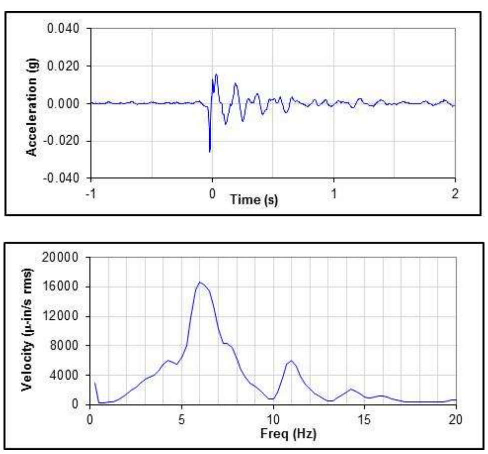
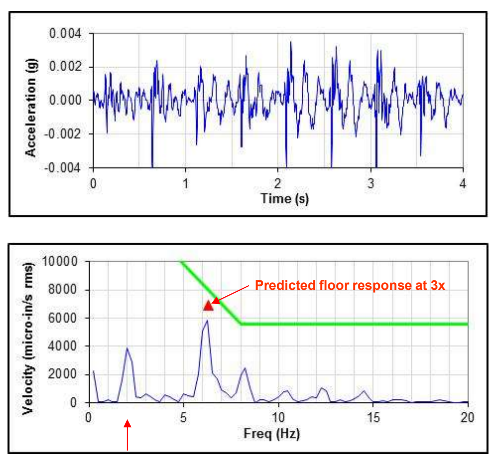
Measurement Results

Heel drop shows a floor frequency near 6.0 Hz



Walking at approx. 2.1 Hz excites the 6.3 Hz floor



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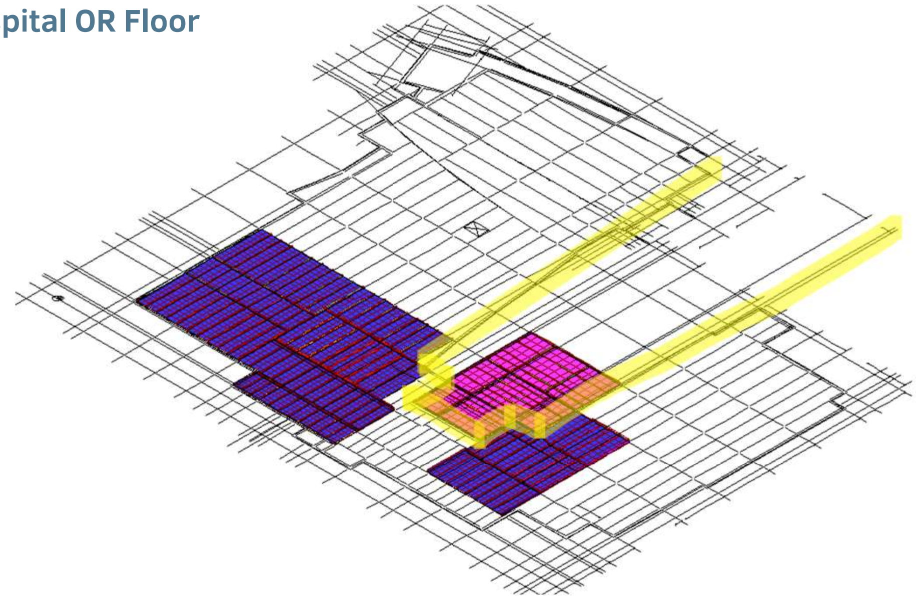
Example 2 – Hospital OR Floor



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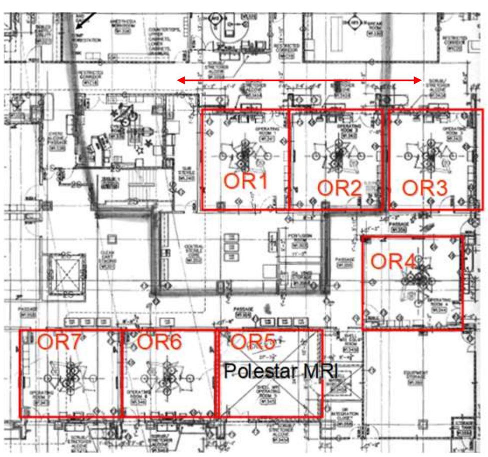
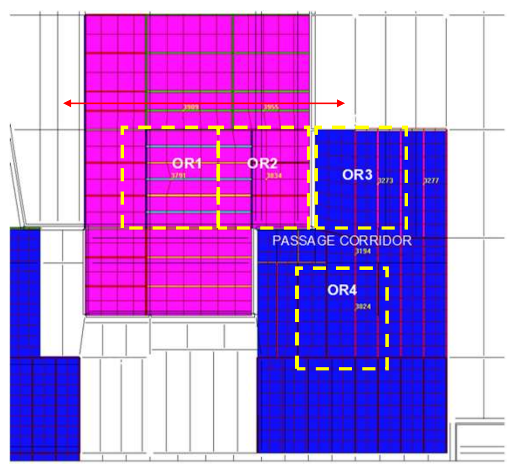
Example 2 – Hospital Floor





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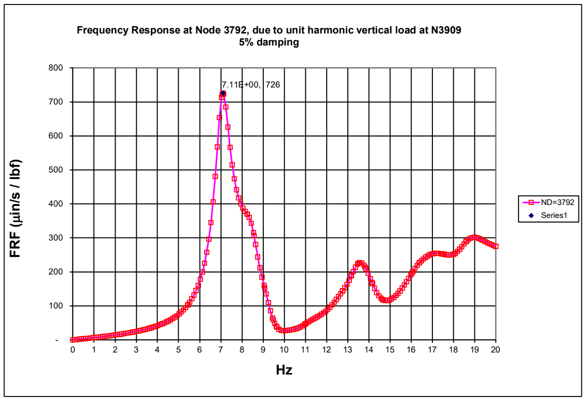
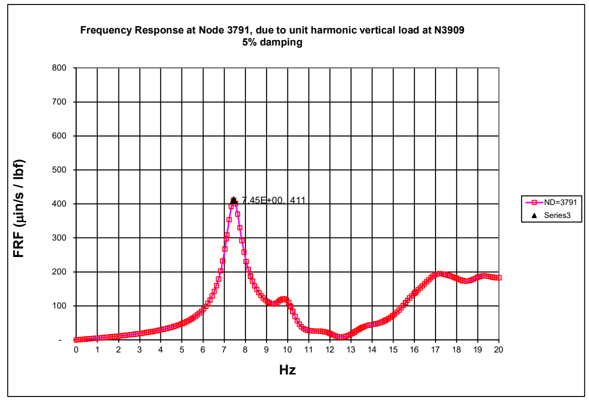
Example 2 – Hospital Floor VC-A

Existing Structure



With Recommended Modifications



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Modifications to the Structure

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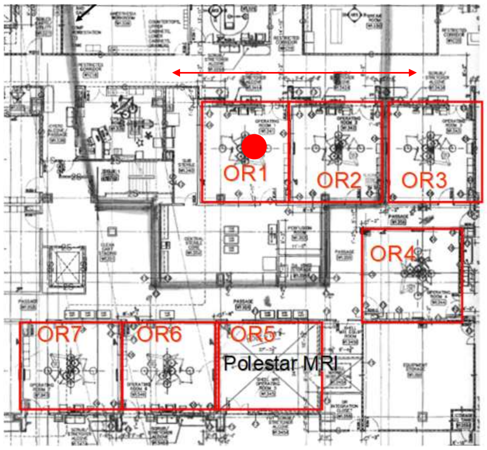
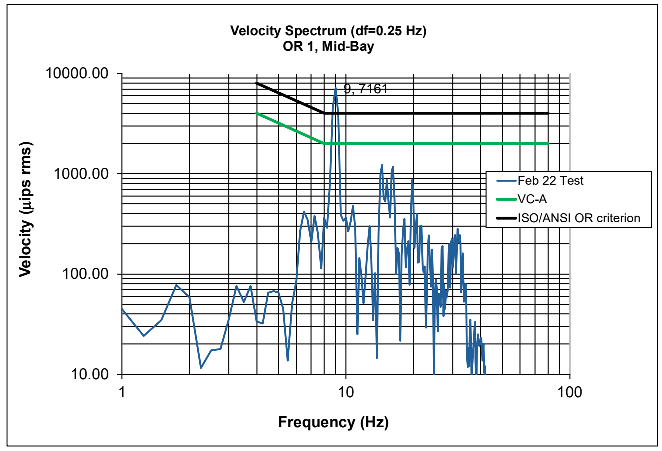
Measured Footfall Vibration After Modifications





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The Problem

- The new beams were not in contact with the deck.

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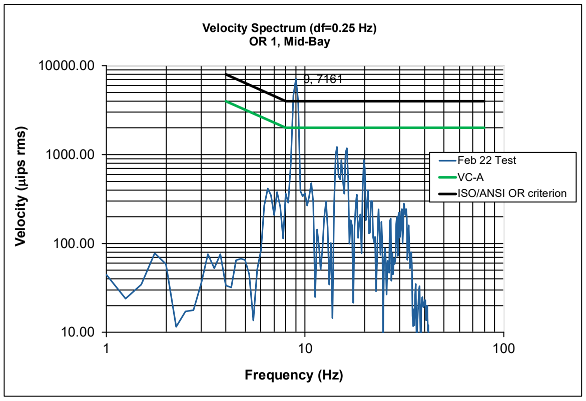
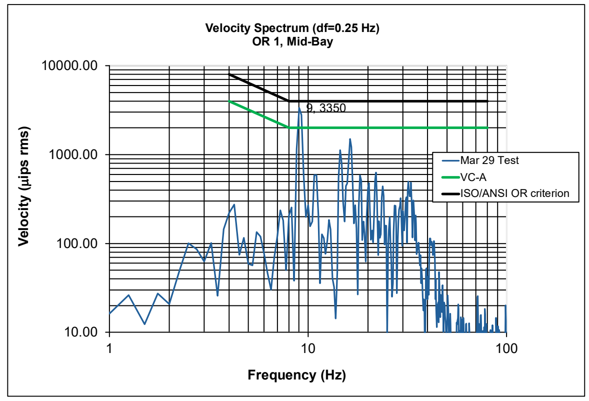
Footfall Vibration Measurements

Before Grouting Beams



2.14x Lower After Grouting Beams



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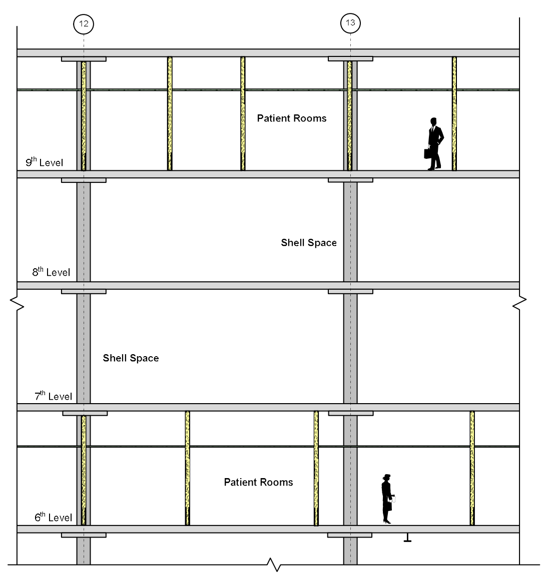
Example 3 – Effect of Gypsum Walls on Footfall Vibration

- 9th Level – gyp walls
- 8th Level – no walls above or below
- 7th Level – walls below



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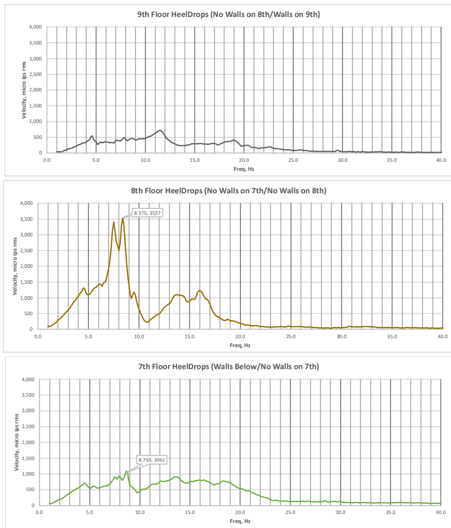
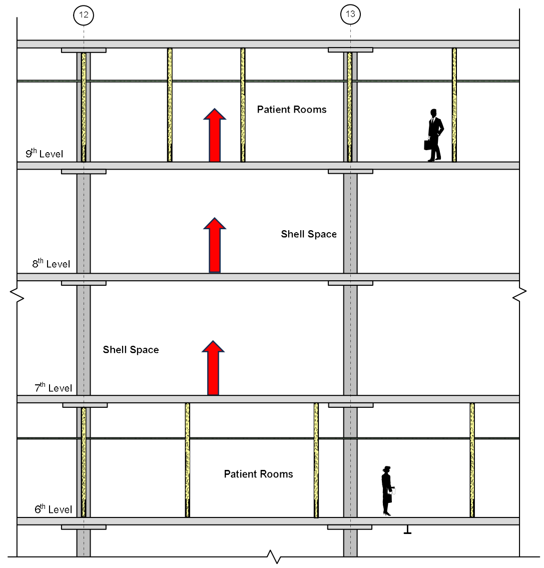
Effect of Gypsum Walls on Footfall Vibration





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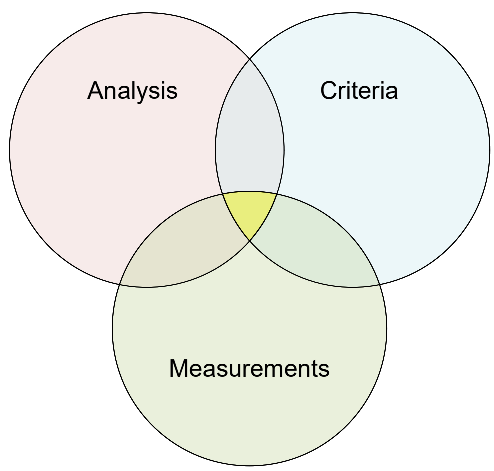
Vibration Serviceability & Measurements
Discussion, Demonstration, Case Studies

- Vibration Serviceability
- Criteria
- Measurements Demo
- Case Studies

Questions?



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Thank you!

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