Mechanical and Footfall Vibration Impact to Healthcare Facilities: Criteria and Design Strategies based on Research and Case Studies

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Overview

- Review of current healthcare facility vibration criteria
- Process of selecting criteria
- Process of selecting design parameters
- Case Study: Surgical microscope and its criteria
- Summary of criteria we use

Current Healthcare Vibration Criteria

- Surgical Suites
  - 100 µm/s (4000 µin/s), as defined by ISO and ANSI (rms one-third octave bands)
  - Misprinted as 200 µm/s (8000 µin/s) in AISC DG 11
- All other spaces require engineering judgment invoking criteria for other types of spaces

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Process of Selecting Criteria (1)

- How is vibration a problem?
  - Human perception
    - Startle
    - Distraction
    - Sleep interference
    - Annoyance
  - Affects instrument performance
    - Degrades instrument performance
    - Introduces errors into data
    - Affects performance of person using instrument

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Process of Selecting Criteria (2)
Vibrations affecting People

- **Startle and distraction** are critical conditions to avoid in surgical suites.
  - ISO and ANSI standards (hence ASHRAE and AISC) use factor of safety (0.5) times human threshold of perception
- **Sleep interference** is an important issue in patient rooms.
  - Sleep environment is basis of ISO/ANSI recommendations for residential-nighttime limit of perception threshold.
- **Annoyance** can be avoided in other areas by use of "office" criterion from ISO, ANSI, ASHRAE, AISC.
  - Allows some perceptible vibration but avoids annoyance range.

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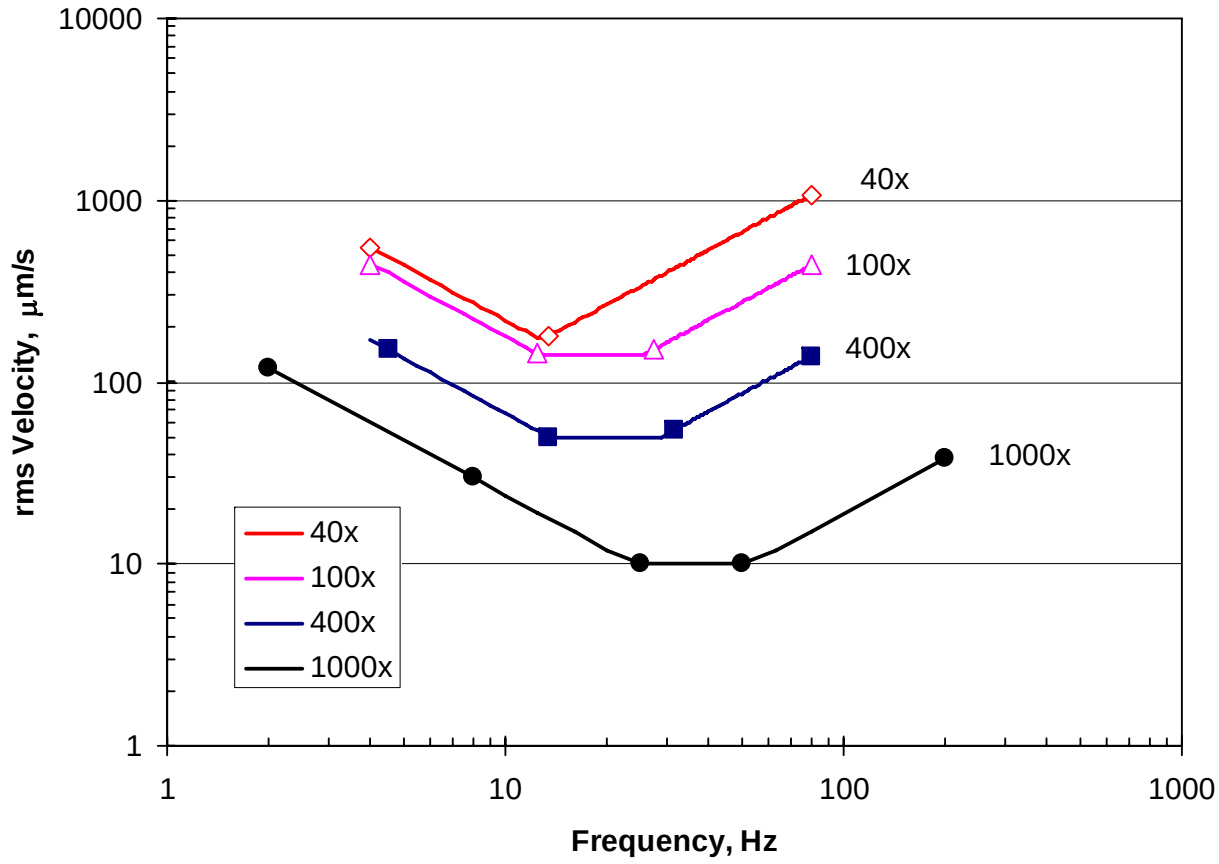
Process of Selecting Criteria (3)
Vibrations affecting Instruments

- Degrades instrument performance; may introduce errors into data. Most likely an issue with imaging (MRI and CT) and lab equipment (commonly microscopes).
  - Where possible, use instrument manufacturers' criteria (MRI, CT, etc.)
  - Criteria for bench microscopes can be based on Amick & Stead, ASHRAE, AISC
- Affects performance of person using instrument. Can lead to eye fatigue or worse (misreading or miscounting in lab tests; errors, nausea or annoyance with surgical microscopes)
  - Only criteria for surgical microscopes are from House & Randell, referenced in AISC; <u>discussed in later slides</u>

Benchtop Microscope Sensitivity, Omnidirectional (Amick & Stead)



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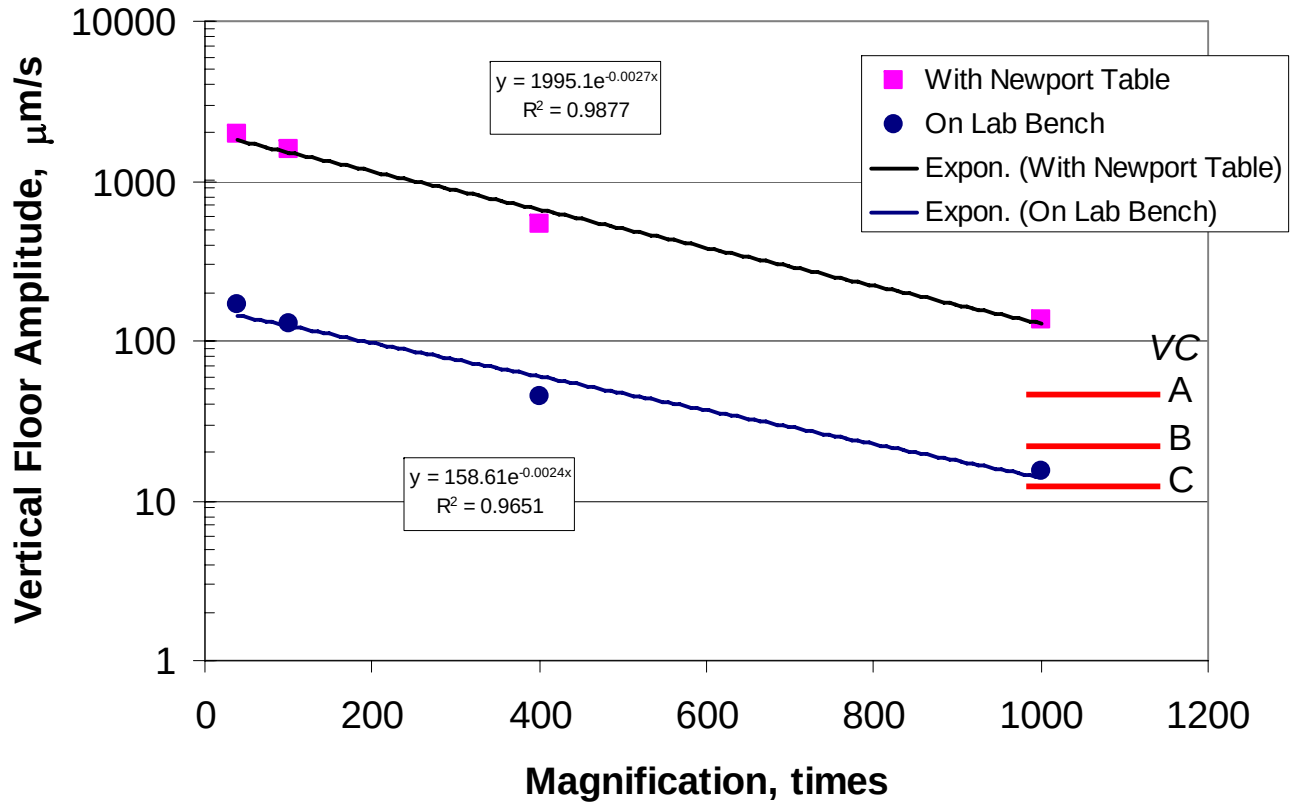
Variation of Vibration Sensitivity with Magnification (Amick & Stead)



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Process of Selecting Design Parameters

- Footfall is generally the critical design parameter
- Mechanical vibrations generally less than those due to footfall unless something is defective or unless floor is very stiff (e.g., Imaging and some MRI suites)
- Consider context in selecting footfall parameters

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Context-dependent Footfall Parameters (1)

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- Footfall forces are a function of pace rate
- Walker pace rate is a function of path and activity
- Path issues
  - **Closed path or corridor:** long path, no obstructions – high walker rate (100 or 120 paces/min, we use 100)
  - **Open path or ghost corridor:** long path, some obstructions – medium walker rate (80 to 85 paces/min, we use 85)
  - **Patient room, lab room, or between lab benches:** short path, obstructions – slow walker rate (70 to 80 paces/min, we use 75)

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Context-dependent Footfall Parameters (2)

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- Walker pace rate is a function of path and activity
- Activity issues
  - **Critical care:** staff often in a hurry in the public corridors – higher walker rate (consider 120 paces/min)
  - **Non-critical care:** staff are less frequently in "hurried" mode in public corridor (consider 100 paces/min)
  - **Patient room:** short path, obstructions – hard to develop the gait associated with fast walker (70 to 80 paces/min, we use 75)

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Context-dependent Footfall Parameters (3)

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- Perform multiple analyses using appropriate walker forces applied at “soft” spots along walker path; base design on the condition creating maximum floor amplitudes
- Vibrations due to walker at 75 ppm in room may be more severe than at 100 ppm in nearby corridor

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Case Study: The “established” criteria may need some rational modification

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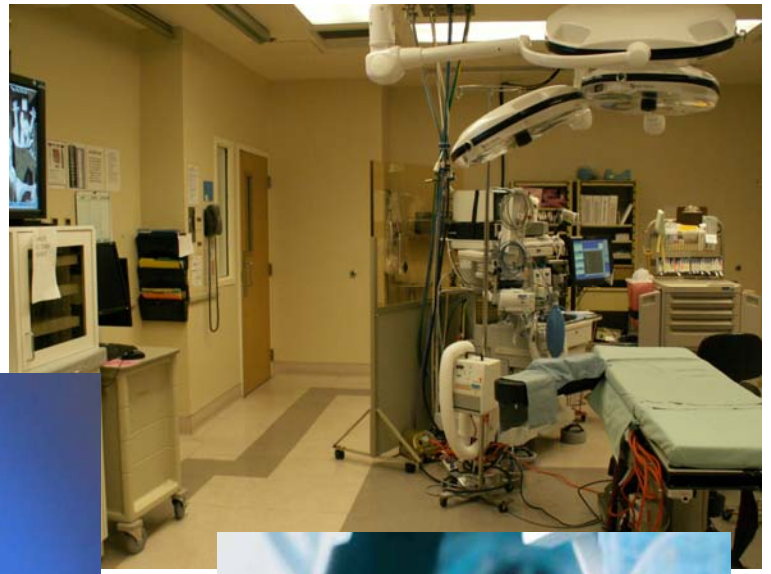
Microscopic Surgery

- Some types of surgery require microscopy (10x to 50x)
  - Ophthalmic
  - Spine



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Criteria?

- ASHRAE
  - "Microsurgery, eye surgery, neurosurgery", use 25 µm/s (1000 µin/s)
- AISC / House & Randell
  - Criterion of 50,000 / M µin/s, where M is magnification, at frequencies between 3 and 8 Hz, relaxed at higher frequencies; use 1250 µin/s (30 um/s) at 40x.
- Amick & Stead
  - Criterion of 100 um/s (4000 µin/s) for benchtop microscope of 40x to 100x

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Case Study Problem

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- Our client: A regional medical center with four operating rooms, two dedicated to microsurgery, using floor-mounted microscopes
  - One Leica, one Zeiss
- “Occasionally” there are vibrations which cause the image to jiggle

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What we found …

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- Nice, stiff, concrete structure
- The “typical” ambient vibration environment in these OR’s was below 50 um/s (2000 µin/s) (OR criterion is 100 µm/s)
- Footfall below 50 um/s (2000 µin/s)
- Steady-state has some acceptable jiggle
- “Problem”—high-amplitude jiggle—occurs a few minutes at a time, a few times a day
- One surgeon routinely experiences nausea during the “problem”

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Routine Floor Measurements (why such a problem?)

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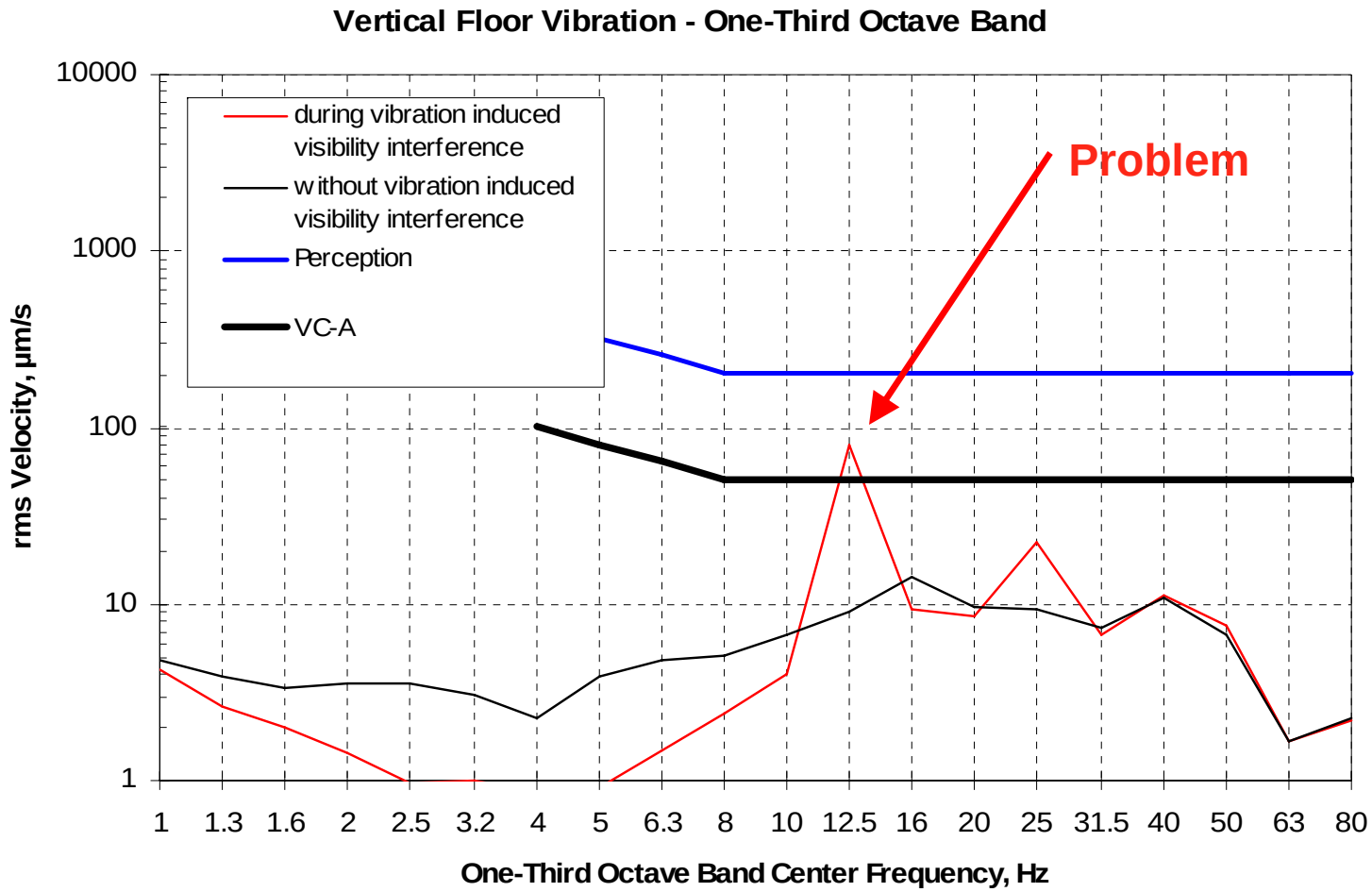

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Compare Floor and Eyepiece (in Narrowband)

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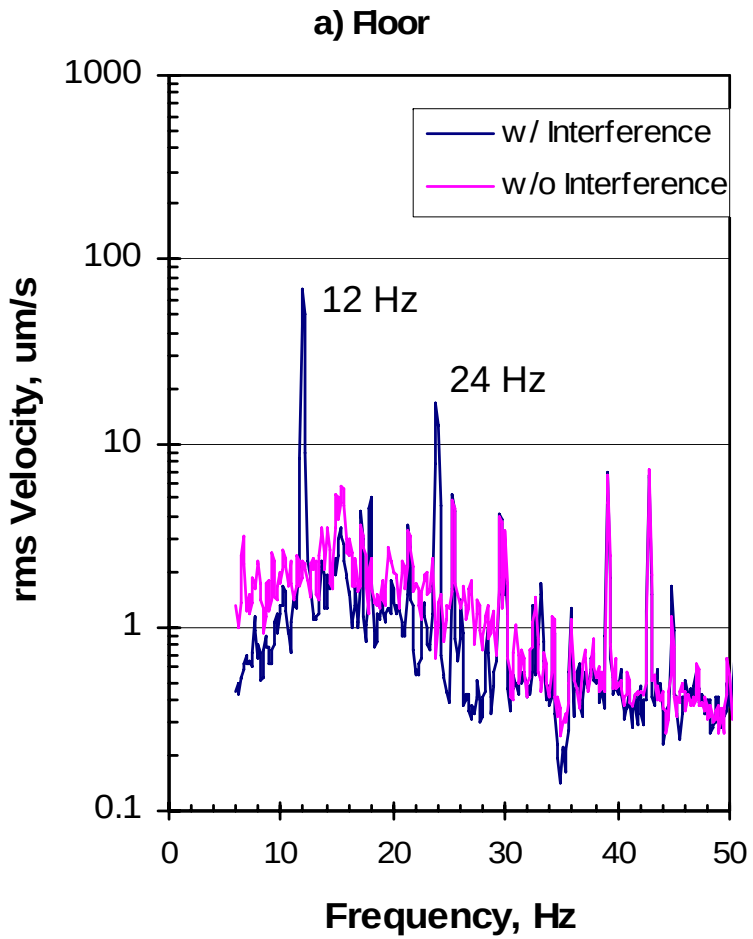
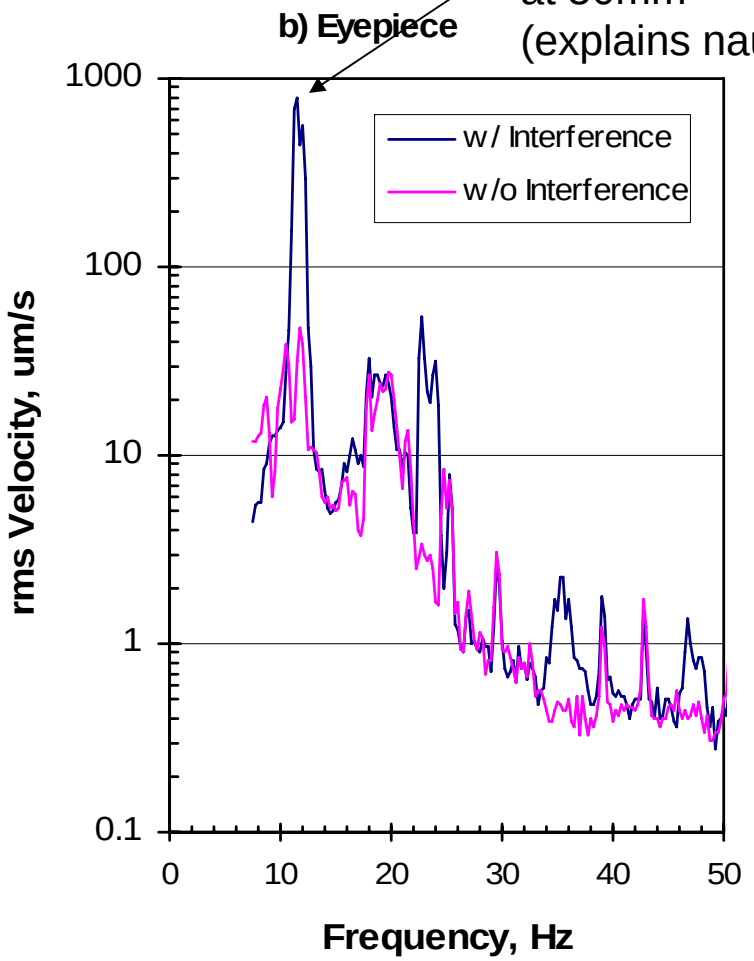
Over 100 arc-sec at 50mm (explains nausea)





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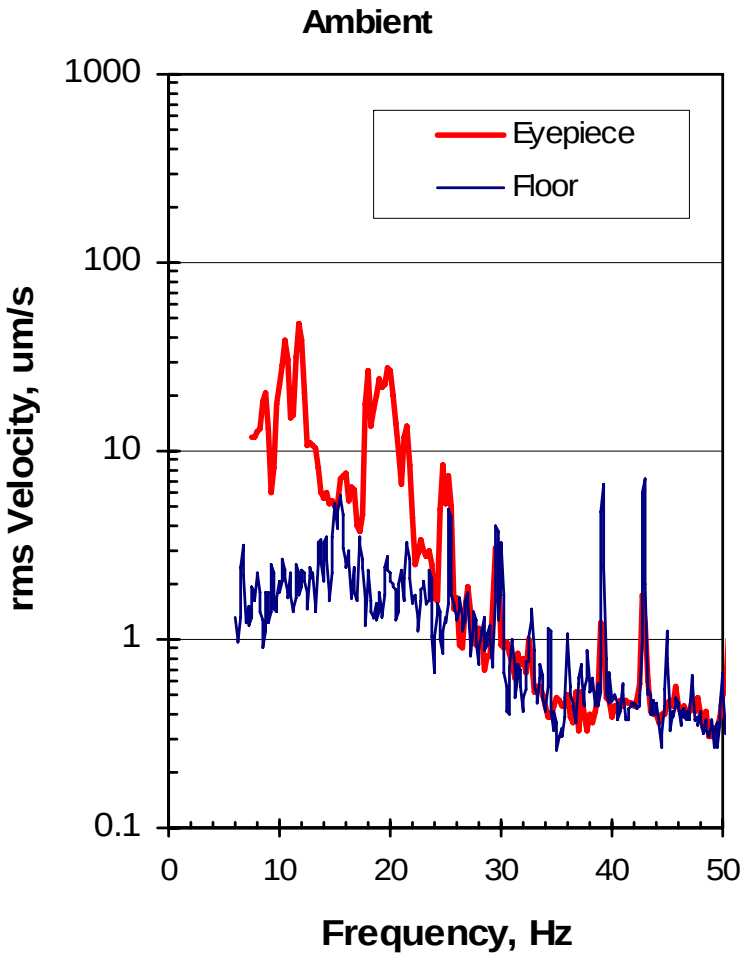

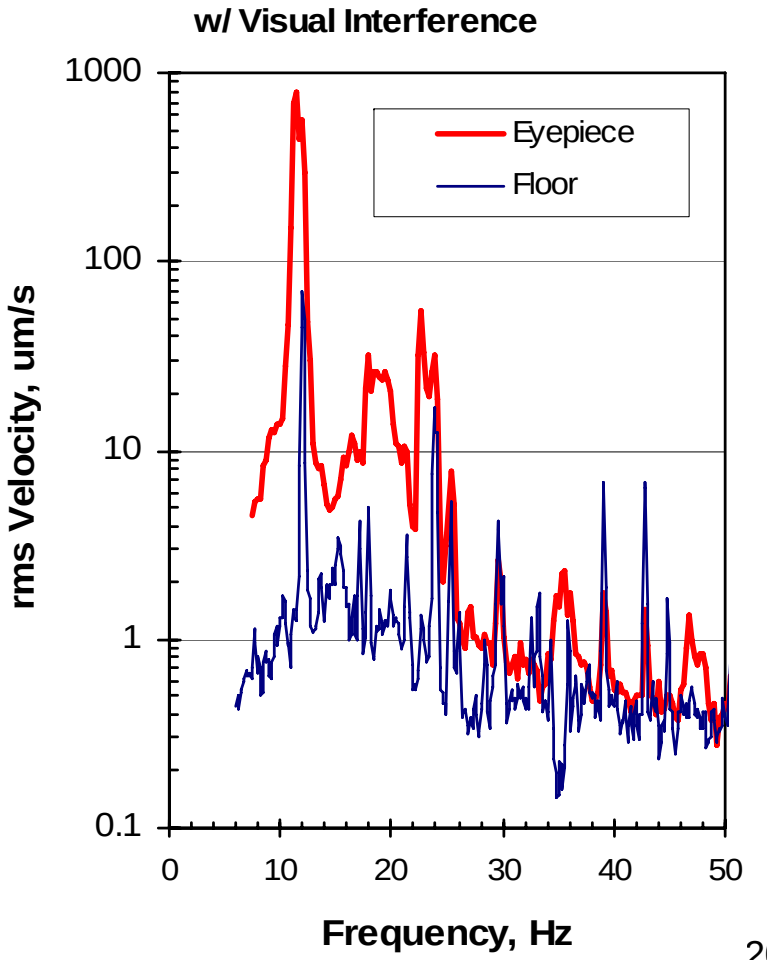

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The Problem …

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- Resonance amplification is a fact of life
  - 8 to12 Hz and 18 to 21 Hz, in this configuration
- Intermittent vibration from mechanical equipment (12.0 Hz and harmonics) *only slightly* exceeded VC-A
- Improve the vibration isolation on the mechanical equipment
- Was VC-A adequate?

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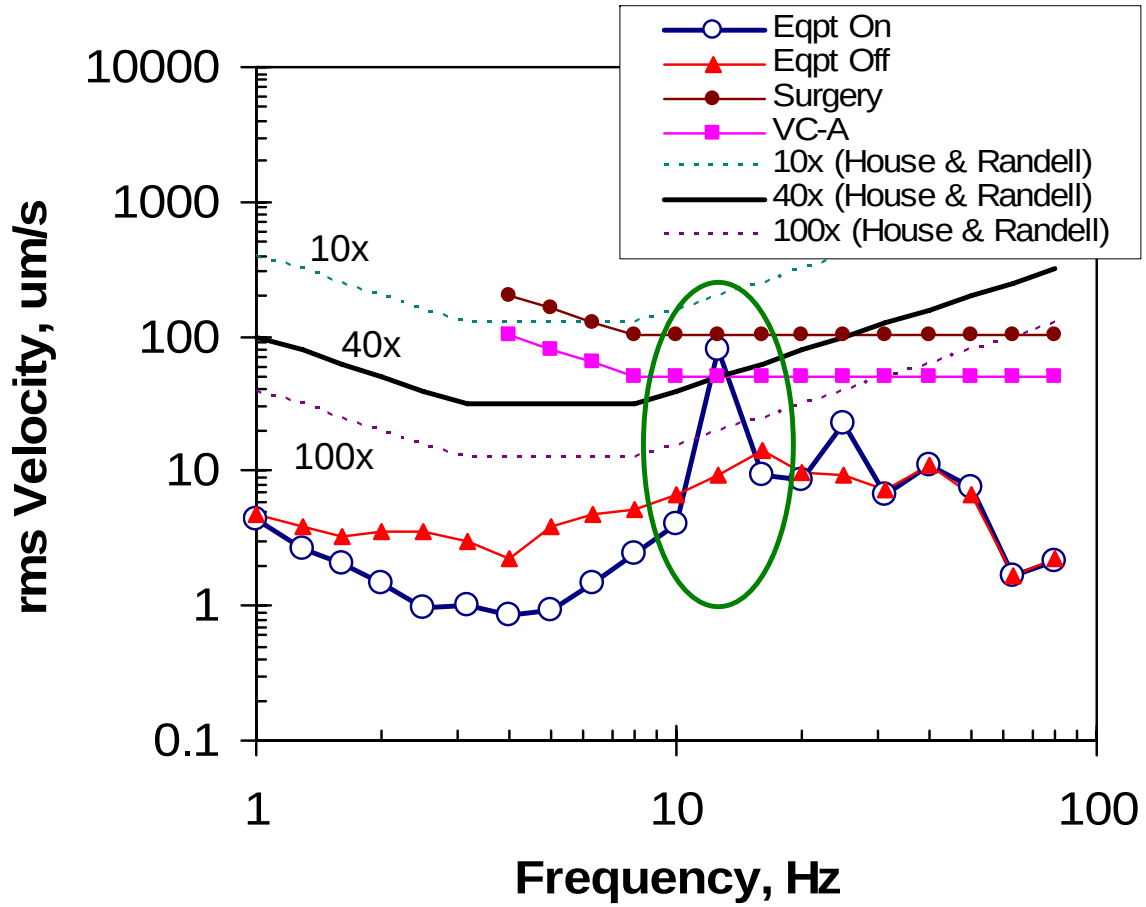
What Criterion is Adequate?



- Surgery criterion *not* adequate
- VC-A and House & Randell 40x are adequate
- Consider extending H&R "dip" to the right or removing relaxation

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Proposed Modification to House & Randell

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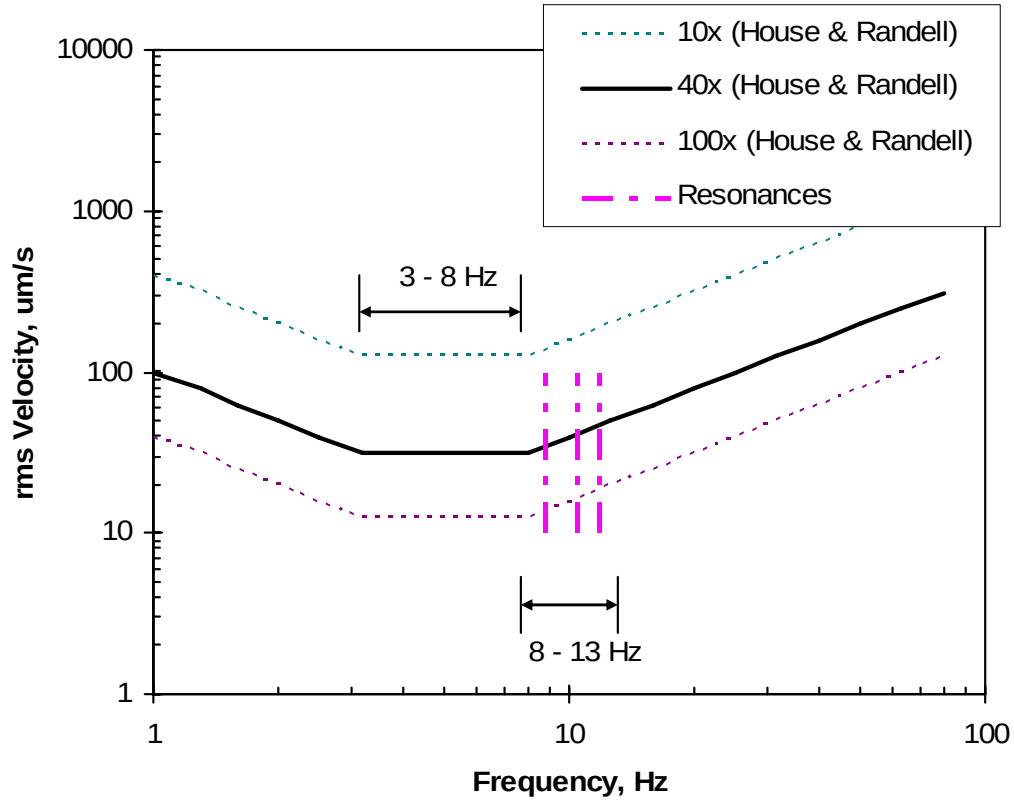

- "Dip" in H&R criterion did not correspond to observed resonances
- Solution:
  - Slide dip to higher frequency
  - Treat as single-velocity criterion, V=1250 / M (where M is magnification)

Vibration Criteria for Hospitals (1)

Type of Space	Primary Factor	Criterion	Rationale
Surgical Suites	Human	100 µm/s (4000 µin/s)	This is defined by ISO and ANSI. The established threshold of human perception is 200 µin/s (8000 µin/s). Historically, the argument was that a factor of safety of 2 against perception avoided the risk of startling the surgeon. [Misprinted as 8000 µin/s in AISC DG 11.Correct in ASHRAE]
Surgical Suites	40x Surgical Microscope *	30 µm/s (1250 µin/s)	AISC DG 11, based on research by House and Randell, validated by Gendreau
Surgical Suites	100x Surgical Microscope *	12.5 µm/s (500 µin/s) (VC-C)	AISC DG 11, based on research by House and Randell
Patient Rooms	Human	200 um/s (8000 µin/s)	This is not specifically defined by international standard (differing from the case for surgical suites), but is based upon the international standard for sleeping areas.

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Vibration Criteria for Hospitals (2)

Type of Space	Primary Factor	Criterion	Rationale
General Labs	Instrument	50 µm/s (2000 µin/s) (VC-A)	This is a consensus standard from a wide variety of sources, including ASHRAE, AISC, IEST, and NIH for generic laboratory space with microscopes up to 400x.
General Labs	Instrument	100 µm/s (4000 µin/s)	This is a relaxed criterion for “non-critical” laboratories with microscopes of 100x or less. Used by many universities for teaching labs (i.e., labs not used for research)
Imaging Labs (MRI)	Instrument	12.5 µm/s (500 µin/s) (VC-C)	Imaging systems vary widely in their sensitivity. The 500 µin/s criterion (approximately) is required to meet the needs of a few of the available systems. By eliminating those from consideration, the criterion can be relaxed.

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References

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- **Amick and Stead:** H. Amick and M. Stead, “Vibration Sensitivity of a Laboratory Bench Microscope,” Sound & Vibration, v. 41, No. 2, pp. 10-17 (February 2007).
- **ASHRAE:** ASHRAE (2003). ASHRAE Handbook: Applications, Chapter 47 (Fig. 39 & Table 40), “Sound and Vibration Control,” 50 pp.
- **House and Randell:** House, M. H., and Randell, R. (1987). “Some Measurements of Acceptable Levels of Vibration in Scientific, Medical and Ophthalmic Microscopes,” *Proc. SPIE Conf. Vib. Con. Opt. and Metrology 732*, pp. 74-80 [V = 1250 / M um/s, where M is magnification]
- **IEST:** Institute of Environmental Sciences and Technology, “Considerations in Cleanroom Design,” RP-CC012.2, 2005.
- **ISO:** International Standards Organization, ISO 2631 "Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration, Parts 1 and 2." Part 1 was updated 15 July 1997 and Part 2 was updated 1 April 2003.
- **NIH:** National Institutes of Health, Office of Research Fachilities (Spring 2003). *NIH Design Policy and Guidelines*