



Todd Busch
CONSULTING

Canadian Society of Iranian Engineers and Architects

Acoustics, Noise and Vibration
Consulting

AN OVERVIEW

27.05.2020

604-1177 Bloor Street East
Mississauga, ON L4Y2N9

647-545-7357
toddbuschconsulting.ca



What will be discussed?



- Introduction to Acoustics
- Professional Background
- Professional Activities
- Overview of Todd Busch Consulting
- Project Classifications
- Markets and Technical Issues
- Questions: 5-Minute Break
- Technical Jargon
- Questions: 5-Minute Break
- Feature Project Presentation

Introduction to Acoustics



- Acoustics: The Science of Sound
 - Air
 - Water
- Noise: Unwanted and/or Undesired Sound
- Vibration
 - Solids
- Characterized by Frequency in Cycle per Second (i.e., Hertz/Hz) and Amplitude or Logarithmic Level
 - Infrasonic (<20 Hz)
 - Sonic (20 Hz to 20,000 Hz)
 - Ultrasonic (>20,000 Hz)
- Decibels are used to Express Logarithmic Levels

Professional Background



- Todd Busch, M.A.Sc., P.Eng., P.E., INCE Bd. Cert.
 - Bachelor of Applied Science
 - Master of Applied Science
 - Diploma in Arts
 - Certificate in Professional Management with Construction Management Specialty
- 24 years professional experience as acoustical consultant, project manager, senior engineer, and sole proprietor of Todd Busch Consulting
- Lived and worked in Vancouver, Los Angeles, San Francisco, San Diego, Calgary, New York, Toronto, and Delhi (currently)
- Graduate thesis studies of noise control / Graduate Supervisor Dr. Murray Hodgson
- Diverse experience with architectural and environmental consulting engineering
- Undergraduate Student Research Award from Natural Sciences & Engineering Research Council
 - Studied Room Acoustics
- Technical writer for National Research Council of Canada
 - Article on Optimizing the Wheel / Rail Interface on behalf of Dr. Joe Kalousek

Professional Activities



- Authored over 50 publications through conferences, peer-reviewed scientific journals, and trade journals
- Canadian Acoustical Association
 - Eckel Student Prize in Noise Control
- Institute of Noise Control Engineers USA
- American Society for Testing of Materials
 - Committee E33 on Building and Environmental Acoustics
- American Society for Heating, Refrigerating and Air-Conditioning Engineers
 - Technical Committee 02.06 Sound and Vibration
- Canadian Standards Association
- Canadian Commission on Building and Fire Codes
 - Task Groups on Sound Transmission and Impact Insulation

Overview of Todd Busch Consulting Services



- Sole Proprietorship Established May 2007
 - Formerly operated in Vancouver 2007-2019, Calgary 2010-2011 and Toronto since 2015
- Architectural Acoustics
- Aviation Noise
- Construction Noise and Vibration
- Highway Noise
- Industrial and Community Noise
- Marine Noise and Vibration
- Mechanical Noise and Vibration
- Military Noise
- Noise and Vibration Monitoring
- Railway Noise and Vibration
- Technology
- Vibration

Overview of Todd Busch Consulting Services



- Sole Proprietorship Established May 2007
 - Formerly operated in Vancouver 2007-2019, Calgary 2010-2011 and Toronto since 2015
- Architectural Acoustics
- Aviation Noise
- Construction Noise and Vibration
- Highway Noise
- Industrial and Community Noise
- Marine Noise and Vibration
- Mechanical Noise and Vibration
- Military Noise
- Noise and Vibration Monitoring
- Railway Noise and Vibration
- Technology
- Vibration

Project Classifications



- Architectural / Built Environment
 - Airports / Ports
 - Education
 - Electromagnetic Fields
 - Healthcare
 - Multi-Unit / Residential
 - Research Laboratories
 - Retail / Commercial / Institutional
 - Semi-Conductor
 - Sports, Recreation, Leisure, Museums & Performing Arts
- Environmental Studies
 - Airports / Ports
 - Education
 - Electromagnetic Fields
 - Healthcare
 - Heavy Rail
 - Industrial / Petrochemical / Power
 - Multi-Unit / Residential
 - Research Laboratories
 - Retail / Commercial / Institutional
 - Roadways
 - Semi-Conductor
 - Sports, Recreation, Leisure, Museums & Performing Arts
 - Telecommunications
 - Transit
 - Urban Land
 - Warehouse / Light Industrial
- Engineering Design & Fabrication
 - Marine
 - Mechanical Contracting
 - Occupational Hygiene
 - Product Testing & Development
 - Stormwater
 - Structural
 - Water Treatment

Architectural Acoustics



- Technical Issues
 - Impact Insulation
 - Noise Control
 - Room Acoustics
 - Sound Transmission
 - Structural Dynamics
 - Vibration Isolation
 - Analysis, Recommendations, Specifications, Design Details, Drawing Review
 - Conceptual, Schematic, Design Development, Construction Documentation, Tendering, Construction Administration, and Commissioning

Aviation Noise



- Technical Issues
 - Outdoor Sound Propagation
 - Measurement of Existing Sound Levels
 - Forecasting of Future Sound Levels
 - Land Use Compatibility Studies
 - Residential Sound Insulation Programs

Construction Noise and Vibration



- Technical Issues
 - Outdoor Sound Propagation
 - Ground-borne Vibration Propagation
 - Noise and Vibration Control
 - Bylaw Compliance
 - Adverse Effects on Sensitive Instrumentation
 - Diagnostic Imaging
 - Research Facilities
 - Microelectronics Manufacturing

Highway Noise



- Technical Issues
 - Outdoor Sound Propagation
 - Ground-borne Vibration Propagation
 - Noise and Vibration Control (e.g., Noise Barriers)
 - Regulatory Compliance
 - Adverse Effects on Adjoining Land Uses
 - Land Use Planning
 - Retrofit Noise Barrier Programs

Industrial and Community Noise



- Technical Issues
 - Outdoor Sound Propagation
 - Noise Control
 - Regulatory Compliance (e.g., Acoustic Assessment Reports in Ontario)
 - Adverse Effects on Adjoining Land Uses
 - Land Use Planning
 - Diagnosis and Ranking of Problematic Noise Sources

Marine Noise and Vibration



- Technical Issues
 - Interior Noise and Vibration Levels
 - Noise and Vibration Control
 - Metal Fatigue and Failure
 - Crew and Passenger Comfort

Mechanical Noise and Vibration



- Technical Issues
 - Interior Noise and Vibration
 - Compliance with Industry Standards, Codes and Regulations
 - Noise and Vibration Control
 - Design of Custom Solutions

Military Noise



- Technical Issues
 - Outdoor Sound Propagation
 - Noise and Sonic Booms
 - Land Use Planning
 - Underwater Acoustics
 - Environmental Studies
 - Residential Sound Insulation Programs
 - American Solution, “The Sound of Freedom”

Noise and Vibration Monitoring



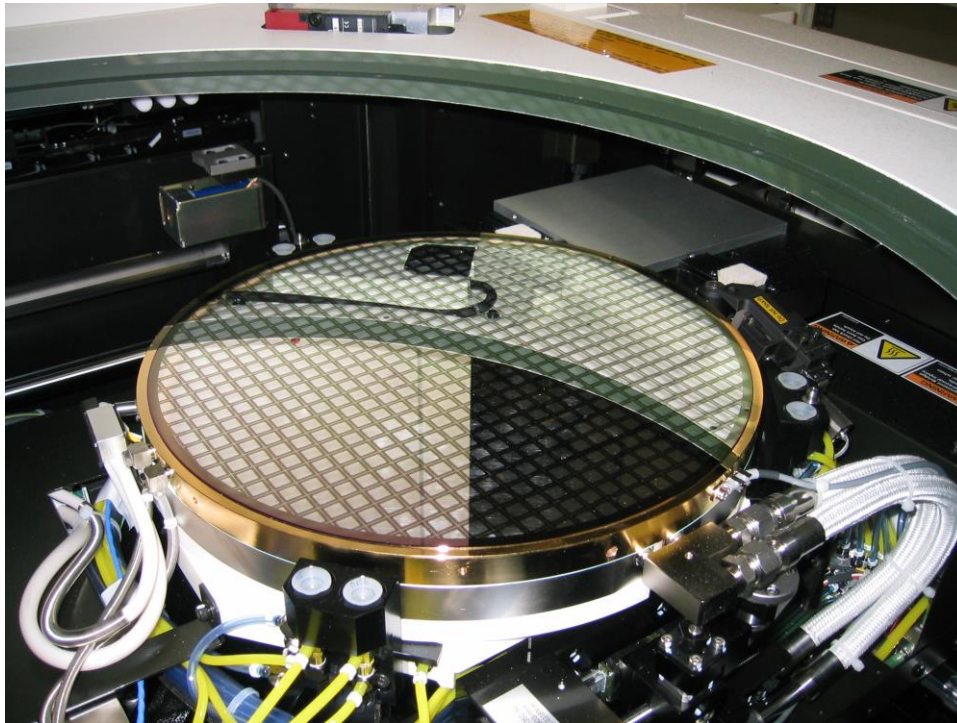
- Technical Issues
 - Cost of Use and Performance of Instrumentation
 - Documenting Baseline Conditions
 - Air, Land, and Sea
 - Compliance with Known Reference Standards (e.g., American National Standards Institute, International Standards Organization)
 - Accuracy, Precision, and Repeatability

Railway Noise and Vibration



- Technical Issues
 - Outdoor Sound Propagation
 - Ground-borne Vibration Propagation
 - Noise and Vibration Control (e.g., Noise Barriers)
 - Regulatory Compliance
 - Adverse Effects on Adjoining Land Uses
 - Land Use Planning
 - Retrofit Noise Barrier Programs

Technology



- Technical Issues
 - Diagnostic Imaging
 - Research Facilities
 - Microelectronics Manufacturing
 - Noise and Vibration Control
 - Measurement of Existing Conditions
 - Forecasting of Future Conditions
 - Product Development

Vibration



- Technical Issues
 - Ground-Borne Vibration Propagation
 - Structural Dynamics (e.g., Floor Vibration)
 - Human Perception
 - Structural Damage Assessments (e.g., Historic Buildings)
 - Various Transportation Modes, and Industrial Sites
 - Vibration Control and Isolation

Questions? 5-minute Break



- Up Next: Technical Jargon
- Feature Project

Technical Jargon



- Sound Pressure/Intensity Level (SPL/SIL)
- Frequency Weighting
- Sound Power Level (PWL/SWL)
- Vibration Acceleration, Velocity, Displacement
- Calibration of Sound and Vibration Instrumentation
- Accuracy, Precision, and Repeatability
- Noise Criteria (NC)
- Vibration Criteria (VC)
- Sound Transmission Class (STC)
- Impact Insulation Class (IIC)

Sound Pressure/Intensity Level (SPL/SIL)

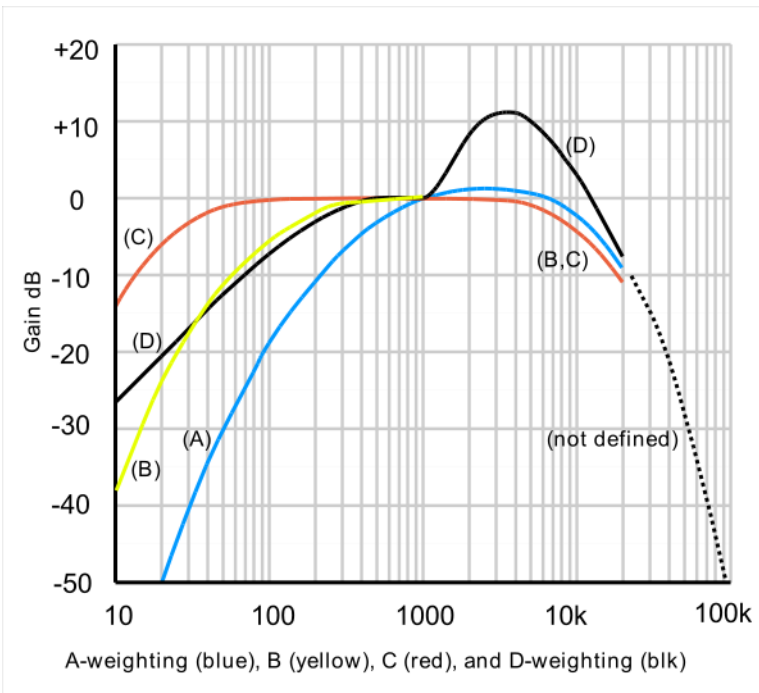
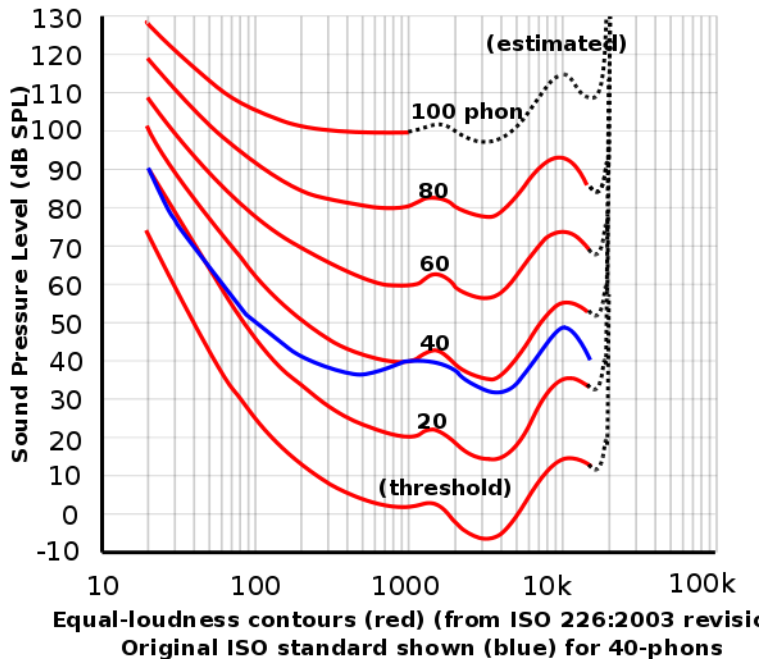


- $SPL = 10 * \log_{10}(p^2/p_{ref}^2)$
- Threshold of Human Hearing in Young
 - $p_{ref} = 20$ microPascals
- 0 dBA
- 130 dBA Pain Threshold
- $SIL = 10 * \log_{10}((I)/(I_{ref}^2))$
- $I_{ref} = 1$ picowatt/m²
- $SIL = SPL - 0.2$
- SPL is Scalar while SIL is a Vector

Frequency Weighting



- Fletcher-Munson Equal-Loudness Curves



- A, B, C, D-Weighting Networks
- Inverse of Equal-Loudness Curves

Sound Power Level (PWL/SWL)



- ASHRAE: PWL
- ISO: SWL
- $PWL/SWL = 10 \cdot \log_{10}(W/W_{ref})$
- $W_{ref} = 1$ picowatt
- 120 dB = 1 Watt of Acoustical Power
- Related to Intensity
 - Power = Area * Intensity
 - $PWL/SWL = 10 \cdot \log_{10}(\text{Area}) + SIL$
 - Measurement at Constant Propagation Distance from Source defines Reference Surface Area

Vibration Acceleration, Velocity, Displacement



- Vibration Level = $10 \cdot \log_{10}(\text{Vibration Amplitude}^2 / \text{Vibration Amplitude Reference}^2)$
- Acceleration, AdB
- Velocity, VdB,
- Displacement, SdB
- ISO Vibration Amplitude Reference
 - Acceleration 1 micrometer/sec²
 - Velocity 1 nanometer/sec
 - Displacement 1 picometer
- USA English Units for Velocity 1 microinch/sec

Calibration of Sound and Vibration Instrumentation



- Sound Calibrator 94 dB = 1 Pa, 114 dB = 10 Pa
- Vibration Calibrator 1 g (i.e., 9.81 m/sec²)

METRIC DERIVATIONS					
	Notes	Vibration Calibrator			
Frequency, Hz		61.4	100	159.2	
Amplitude, g		1	1	1	
Amplitude, m/s ²		9.81	9.81	9.81	
Amplitude, m/s	Divide Acceleration by 2 PI f	0.025428501	0.015613	0.009807	
Amplitude, m	Divide Velocity by 2 PI f	6.59132E-05	2.48E-05	9.8E-06	
Acceleration	1 µg	0.000001	0.000001	0.000001	
ISO Reference, Acceleration	1 µm/s ²	0.000001	0.000001	0.000001	
ISO Reference, Velocity	1 nm/s	0.000000001	1E-09	1E-09	
ISO Reference, Displacement	1 picometer	1E-12	1E-12	1E-12	
		Calibration Levels			
Acceleration	re: 1 µg	120	120	120	
Acceleration	re: 1 µm/s ²	139.8	139.8	139.8	
Velocity	re: 1 nm/s	148.1	143.9	139.8	
Displacement	re: 1 picometer	156.4	147.9	139.8	

Accuracy, Precision, and Repeatability

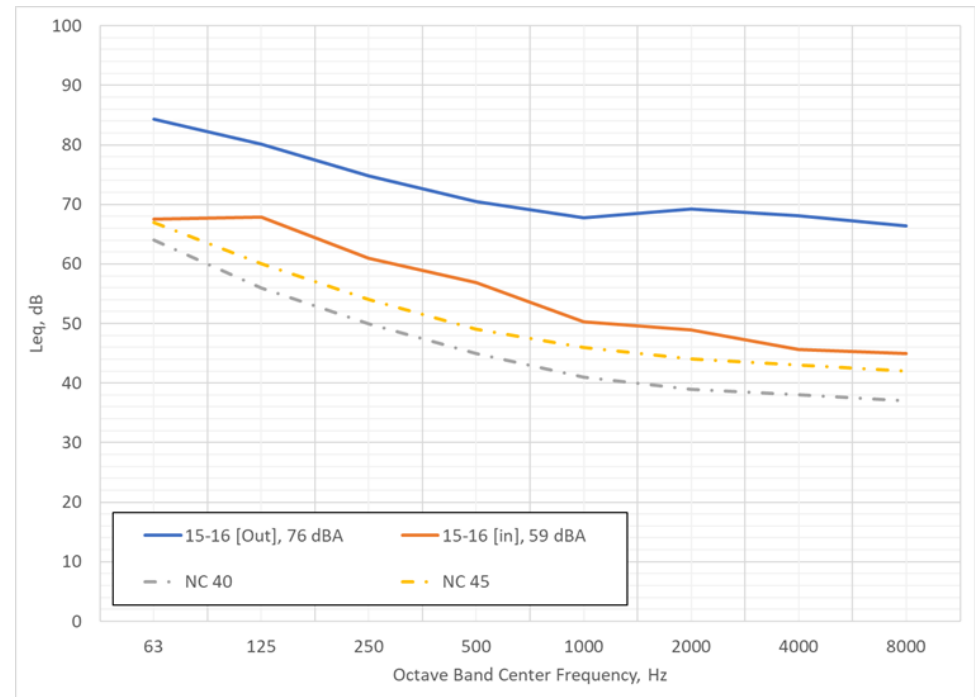


- Accuracy
 - American National Standards Institute (ANSI) Type 1 and/or International Electrotechnical Commission (IEC) Class 1 Instrument ± 0.7 dB
 - Type 2 ± 2 dB
- Precision (e.g., 100 dB, 100.1 dB, 100.01 dB, etc.)
 - Human Perception in Laboratory Limited to ± 1 dB
- Repeatability
 - Accuracy When Instrument Exposed to Exactly the Same Measurement Signal and Conditions on Par with Type 1 or Type 2 Classification

Noise Criteria (NC)



- NC Published in 1957 by Leo Beranek
 - Octave Bands from 63 Hz to 8000 Hz
- Promulgated by ASHRAE
 - Alternative Room Criteria (RC)
 - Balanced Noise Criteria (NCB)
- Noise Rating (NR) similar to NC



Vibration Criteria (VC)



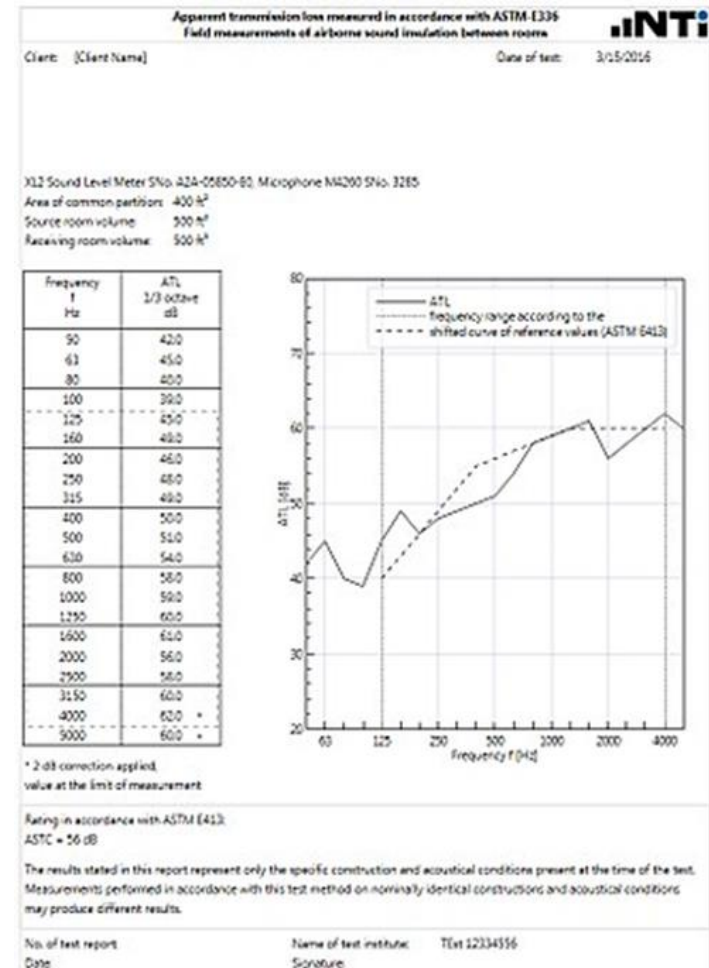
- VC Published in 1991 by Colin Gordon
 - 1/3-Octave Bands from 4 Hz to 100 Hz
- Promulgated by ASHRAE
- Applicable to Human Perception, Diagnostic Imaging, Research Laboratories, and Microelectronics Manufacturing

Criterion Curve (see Figure 1)	Max Level (1) microinches/sec (dB)	Detail Size (2) microns	Description of Use
Workshop (ISO)	32000 (90)	N/A	Distinctly feelable vibration. Appropriate to workshops and nonsensitive areas.
Office (ISO)	16000 (84)	N/A	Feelable vibration. Appropriate to offices and nonsensitive areas.
Residential Day (ISO)	8000 (78)	75	Barely feelable vibration. Appropriate to sleep areas in most instances. Probably adequate for computer equipment, probe test equipment and low-power (to 50X) microscopes.
Op. Theatre (ISO)	4000 (72)	25	Vibration not feelable. Suitable for sensitive sleep areas. Suitable in most instances for microscopes to 100X and for other equipment of low sensitivity.
VC-A	2000 (66)	8	Adequate in most instances for optical microscopes to 400X, microbalances, optical balances, proximity and projection aligners, etc.
VC-B	1000 (60)	3	An appropriate standard for optical microscopes to 1000X, inspection and lithography equipment (including steppers) to 3 μ line widths.
VC-C	500 (54)	1	A good standard for most lithography and inspection equipment (including electron microscopes to 1 μ detail size.
VC-D	250 (48)	0.3	Suitable in most instances for the most demanding equipment including electron microscopes (TEMs and SEMs) and E-Beam systems, operating to the limits of their capability.
VC-E	125 (42)	0.1	A difficult criterion to achieve in most instances. Assumed to be adequate for the most demanding of sensitive systems including long path, laser-based, small target systems and other systems requiring extraordinary dynamic stability.

Sound Transmission Class (STC)



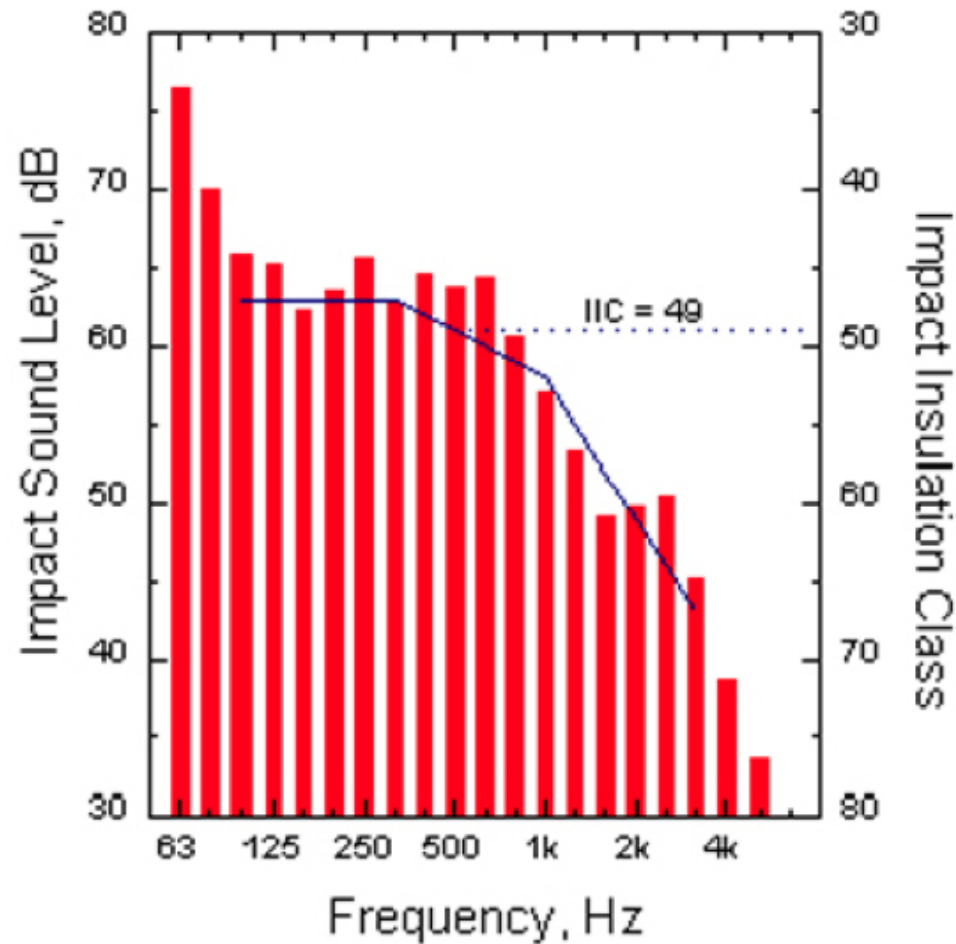
- Assessed in 1/3-Octave Bands from 125 Hz to 4000 Hz using Transmission Loss (TL)
- Reference Contour
- ASTM E90
 - Laboratory STC
- ASTM E336
 - Apparent STC (ASTC)
- National Building Code of Canada Requirement



Impact Insulation Class (IIC)



- Assessed in 1/3-Octave Bands from 100 Hz to 3150 Hz using Transmission Loss (TL)
- Reference Contour
- ASTM E989
 - Laboratory IIC
- ASTM E492
 - Tapping Machine
- National Building Code of Canada Not Required



Questions? 5-minute Break



- Up Next: Feature Project

Acoustics, Noise, and Vibration for Nanotechnology

Presented May 27, 2020 by

Todd Busch

M.A.Sc., P.Eng., P.E., INCE Bd. Cert.

Nanotechnology

- Science, engineering, and technology conducted at the nanoscale, which is about 1 to 100 nanometre.
- Research using scanning tunneling microscope (STM) and the atomic force microscope (AFM).
- Imaging, Characterization, Fabrication.

National Institute for Nanotechnology



- June 22, 2006.
- Canada's "Quietest" Research Lab.
- Acoustics, Noise, and Vibration.

Engineering & Construction Team

- National Research Council of Canada / University of Alberta.
- Project Management: Stantec.
- Designers: Cohos Evamy Partners.
- Mechanical/Electrical: Hemisphere Engineering.
- EMF/EMI: Vitatech.
- Construction Management: PCL.
- Acoustical Consultant: Colin Gordon & Associates.

Top Facility Priorities

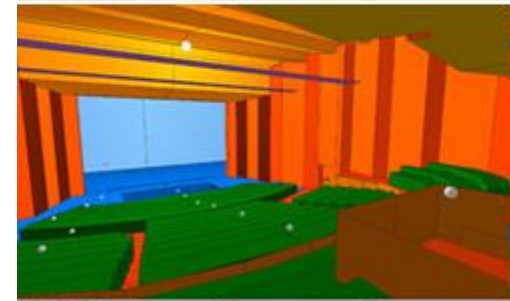
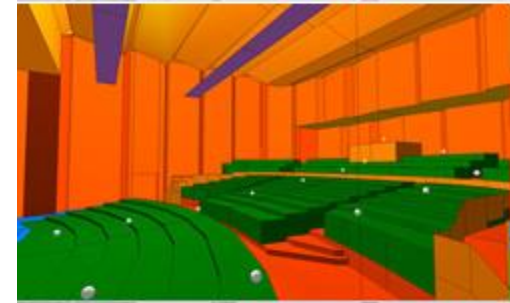
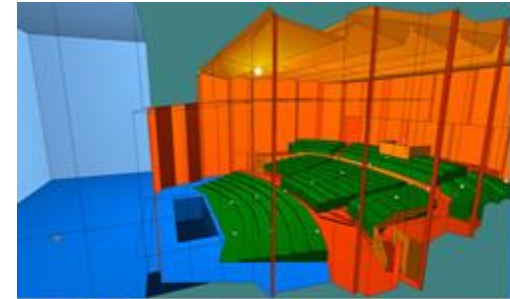
- Maximizing Space Use
- Renovations, Upgrades, Construction
- Reducing Building Operating Costs
- Energy Use & Sustainability
- Finding New Funding Opportunities

Acoustics is Applicable to All Major Design Disciplines

- Architecture & interior design
 - Space planning, rooms, exterior shell & partitioning
- Structural engineering
 - Vibration from outside & inside sources
- Mechanical & electrical engineering
 - Resilient isolation, silencers & specifications

Architectural Design

Reverberation control	▶
Calculate background sound within rooms due to exterior and interior sources	▶
Room adjacencies that necessitate greater (or lesser) noise control	▶
Partition / door selection for sound isolation	▶
Impact-noise reduction	▶
Floor-ceiling design options	▶
Open-plan areas and speech privacy	▶



Partition Selection

Walls, Interior Ceilings

Transmission Loss (TL) for octave or third-octave bands

Measure of reduction of airborne sound

Sound Transmission Class (STC) single number representation of TL

Works best for speech in 500 Hz, 1000 Hz bands

Doesn't account for structural vibration

MEPP/HVAC&R Design

Review project design for compliance with required application of the provisions for sound and vibration control of the Alberta Building Code 2006.	◀
Specification of balancing requirements for rotating equipment, as necessary in order to reduce the vibration of building systems.	◀
Limitations on sound emissions from equipment, such as heating, ventilating and air-conditioning units, diffusers, electrical transformers, and standby generators.	◀
Required vibration-isolation hardware, such as spring type, base type, and minimum static deflection for isolators, with known and field-tested performance history.	◀
Details of the isolation of piping and ductwork as necessary to control transmission of energy from these to the structure.	◀
Vibration-isolation schedules that list each significant piece of equipment, along with equipment-specific isolation requirements that are determined knowing the location, mechanical power and other equipment characteristics.	◀
Review of bid specifications related to MEP equipment, to ensure that these adequately reflect project vibration-design requirements.	◀

Vibration Isolation Schedule

Section 15240 Isolation at Source

Mechanical, Plumbing, Ductwork

Requires Vendor Input to Identify Products

Mason Industries

Vibron (Kinetics subsidiary)

Vibro-Acoustics

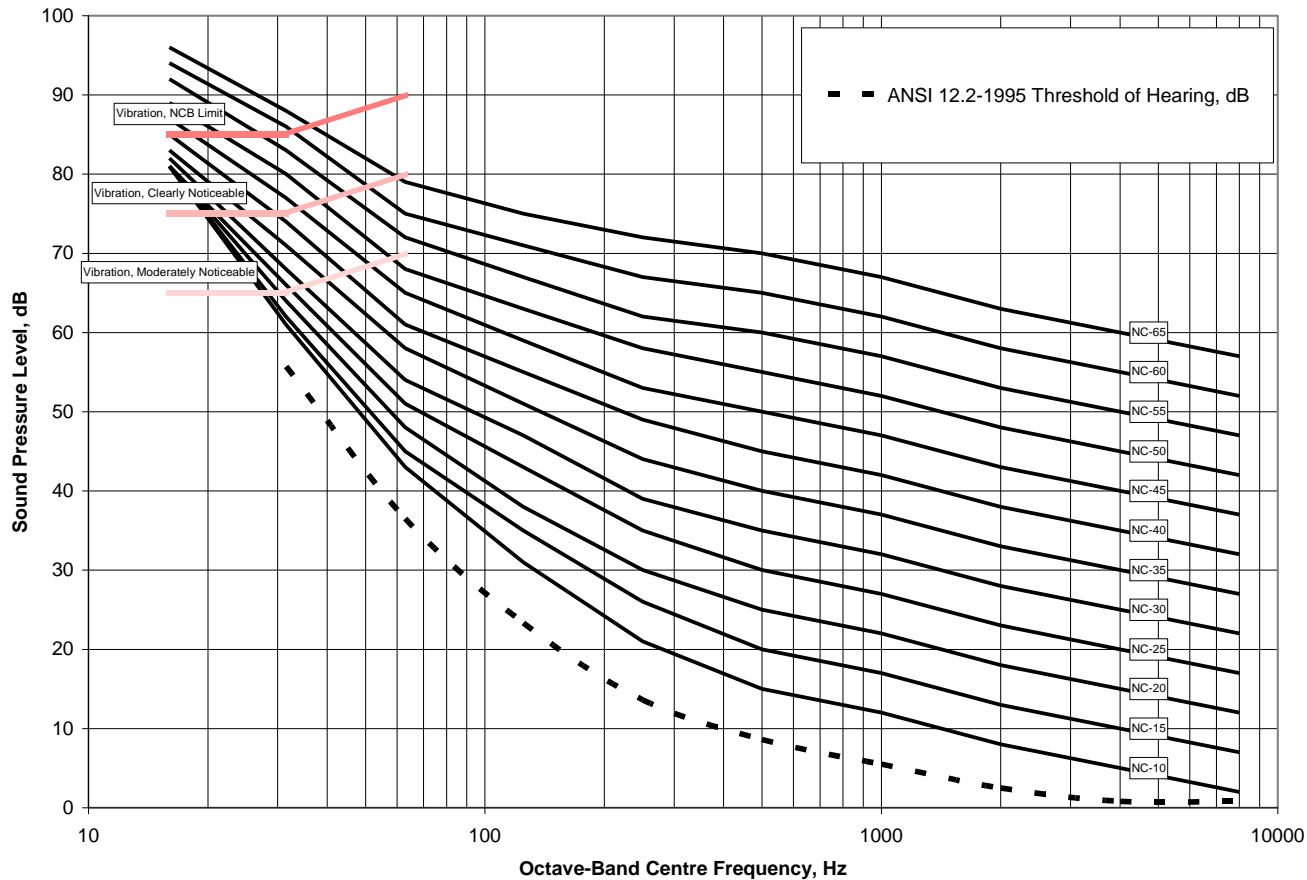
Edits in Progress, Area Specific Guidelines?

Attach to Bid Documents

Electrical

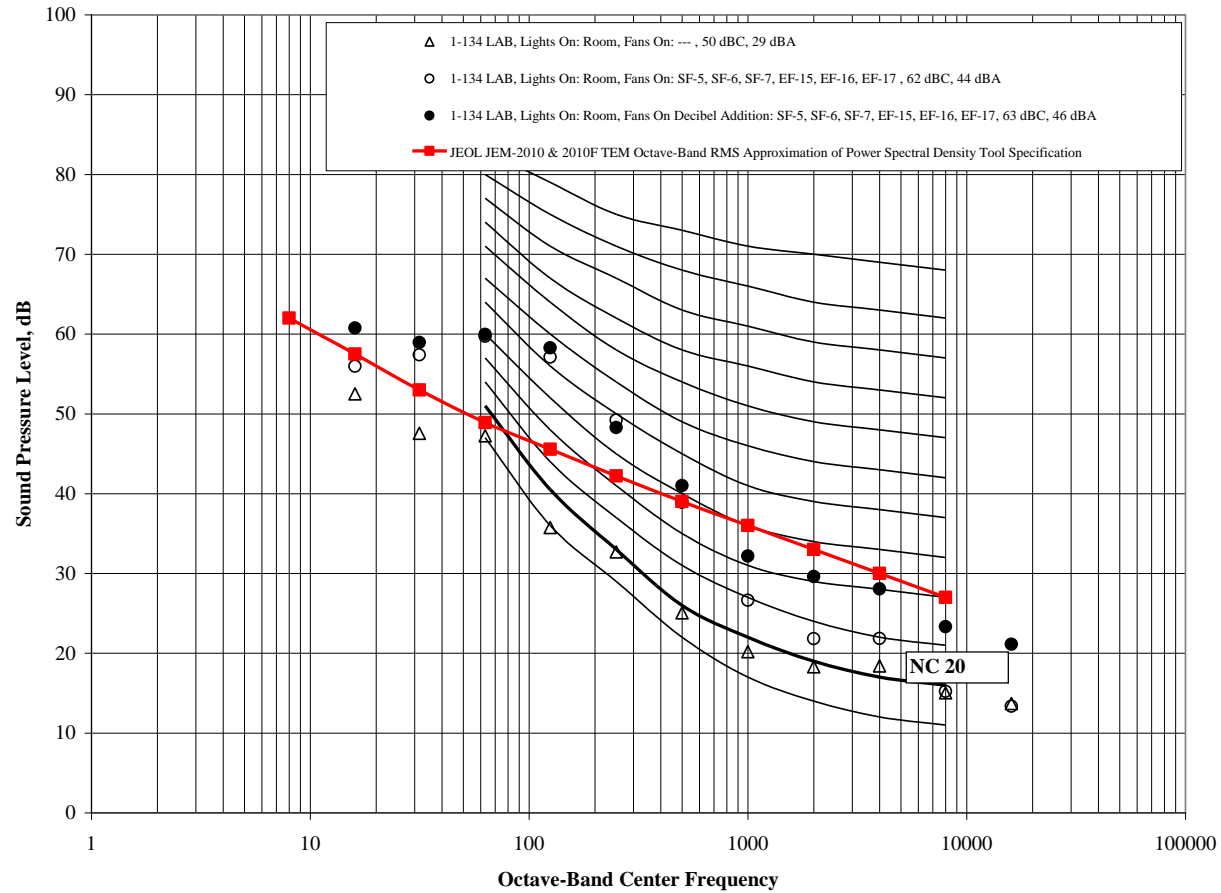
Interior Ceilings (Mechanical Plenum, Characterization Suite)

Balanced Noise Criteria (NCB)



Alternative to Room Criteria (RC), see ASHRAE

Initial Testing Characterization Suites



Air Handler Unit Noise

Noise Emission Limit using Sound Power Level (SWL)

Eight AHU Inlet/Outlet to consider

Design Improvements

- Internal Vibration Isolation

- Flow Straightening Devices

- Perforated Metal

Witness Testing using Sound Intensity

Characterization Suite, Low NC Rooms,
Equipment Noise Sensitivity

Fume Hood Noise

Evaluated for 6th Floor Engineering Lab and 2nd Floor Synthetic Chemistry

Limit SWL of Exhaust Fans

Reduce Flow Velocity within Ductwork

Limit Sound Pressure Level (SPL) of Supplied Fume Hood Unit

42 dBA @ 1 m Feasible to help achieve NC 45 overall

Acoustic Lining within Ductwork not Feasible

Community Noise

NINT Fume Hood Exhaust Stacks

City of Edmonton Bylaw

Section 401 reads “No person shall cause, or permit to be caused, noise of a level exceeding 50 dBA in a residential district at night.” Nighttime hours are from 22:01 to 07:00. The sound level meter is to be configured to the “fast” damping response.

Fume Hoods Exhausts Look OK

Inlets/Outlets for Rooftop Equipment

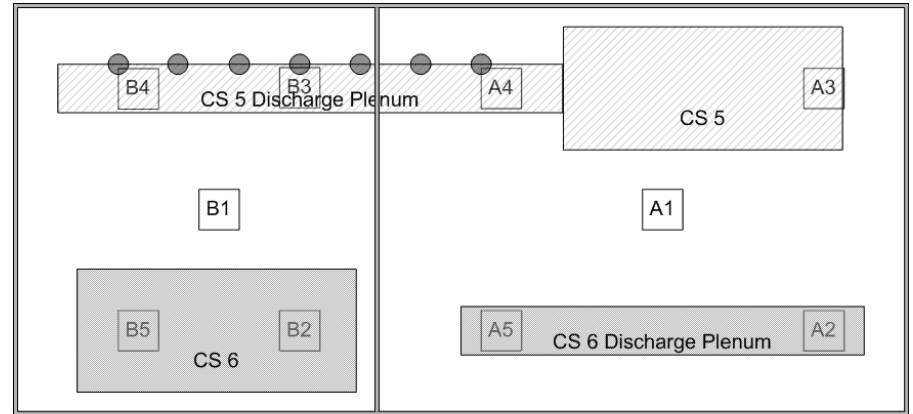
SWL Limits

Cleanroom Air Handlers

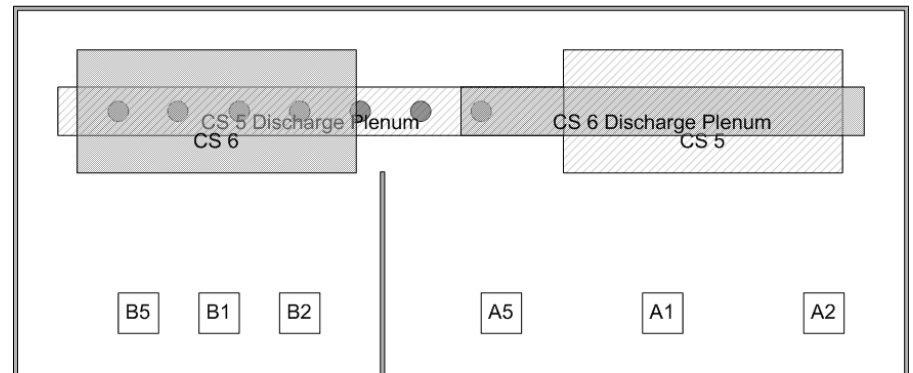
- Class 1000 environment
 - No fibrous materials exposed to airflow
- Included:
 - Low-noise plenum fan
 - Inlet/discharge silencers
- Fabricated outside of specified noise-emission levels.
- Modified in place to incorporate perforated sheet-metal lining within plenum



Post-Modification Testing Cleanroom Geometry

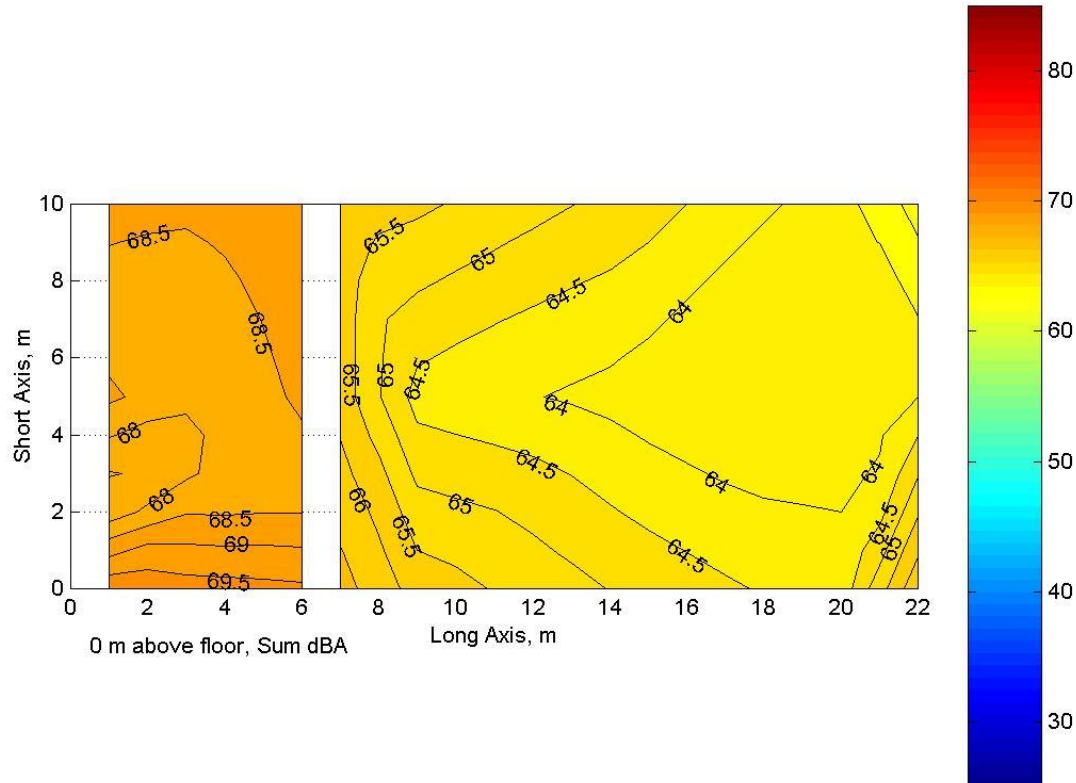


PLAN VIEW, APPROXIMATELY 22 m by 10 m



ELEVATION VIEW, APPROXIMATELY 22 m by 9 m

Post-Modification Testing Cleanroom Results

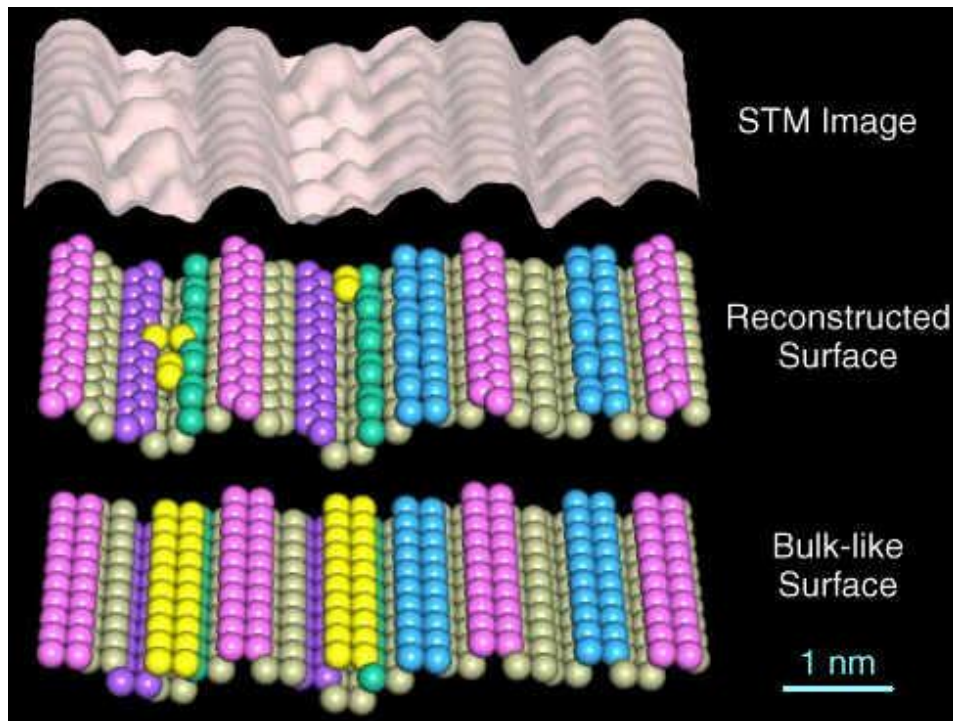


Structural Design

Review most-recent design drawings to identify apparent deviations from earlier recommendations and specifications for sound and vibration control.	▶
Perform calculations to estimate the vibration response of structures due to footfalls, building systems and processes. Not related to compliance for seismic-code issues.	▶
Review the significance of structural design with regard to the installation and support of mechanical and electrical systems as they directly relate to sound and vibration control.	▶



Effects in Nanotechnology



STM system “maps” a surface

Computer reconstructs a molecular pattern to “fit” the surface

Vibrations will introduce additional “ripples” which may be interpreted as additional molecular pattern

Vibration Sources

Ambient Conditions of Site

Traffic, Nearby buildings and their CUPs

Mechanical Systems

HVAC; Exhaust; Water & vacuum pumps

Piping, Ducting

Personnel Activities

People walking, Carts, Moving N₂ Bottles

Preferences

Frequency domain

Majority of practitioners use FFT for diagnostics and 1/3 octave band for assessment

Also used: FFT alone, PSD

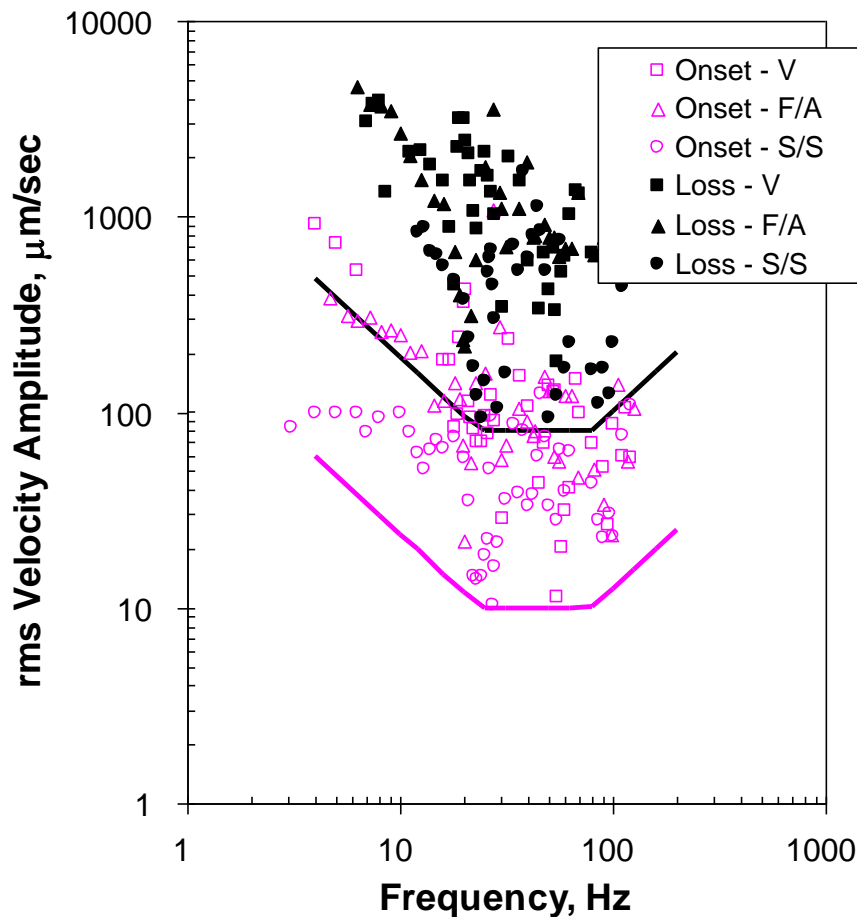
Response spectra *not* used (but being considered by ISO committee)

Energy Average statistics; RMS amplitude

We use velocity

(With spectra, the actual metric isn't critical as long as it is defined.)

Vibration Criteria (1)



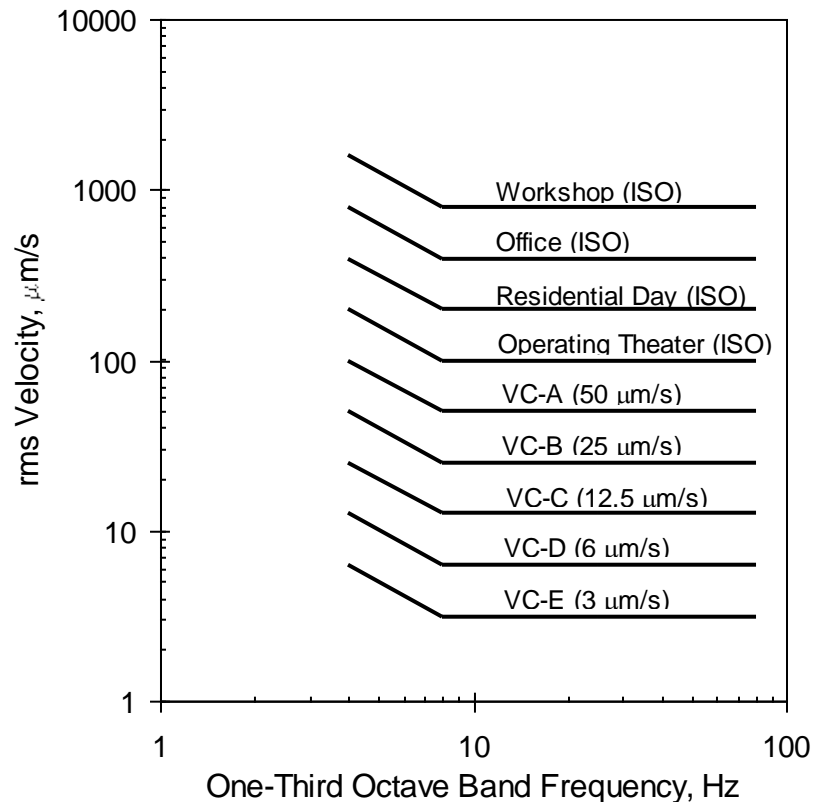
Instrument-Specific Criteria

Shake at many frequencies and in three directions

Observe output degradation

Identify boundaries

Vibration Criteria (2)



Common practice to use “Generic” criteria

Popular set (VC, formerly “BBN”) shown at left

In some cases, “knee” at 8 Hz is eliminated and criterion is flat down to 1 Hz

Design to Minimize Vibration

Identify sensitive equipment

Select one or more vibration criteria

Identify vibration source(s)

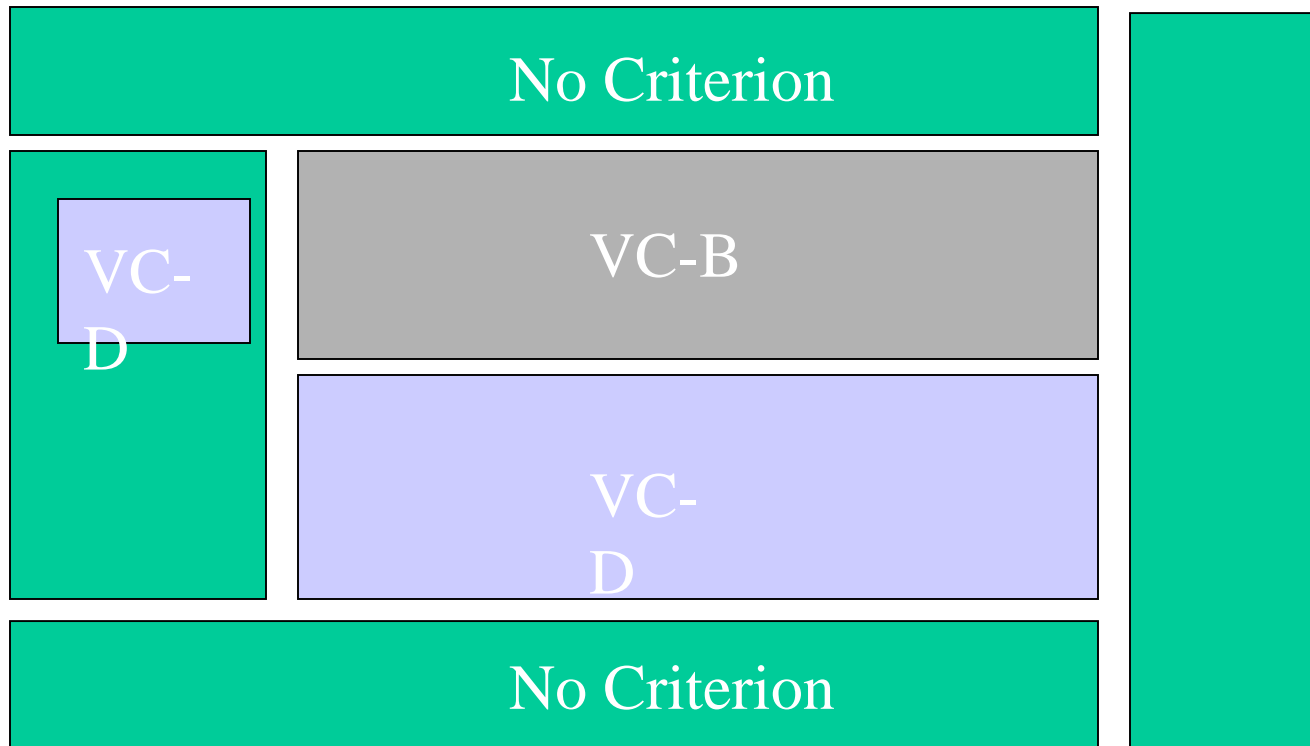
Identify the controlling structural components

Model the structure and/or component, predict performance

Modify design

Iterate

Identify Critical Areas in Building, Assign Criteria



Structural Components

Floors Supporting Sensitive Equipment

Columns Supporting Sensitive Floors

Shear Walls

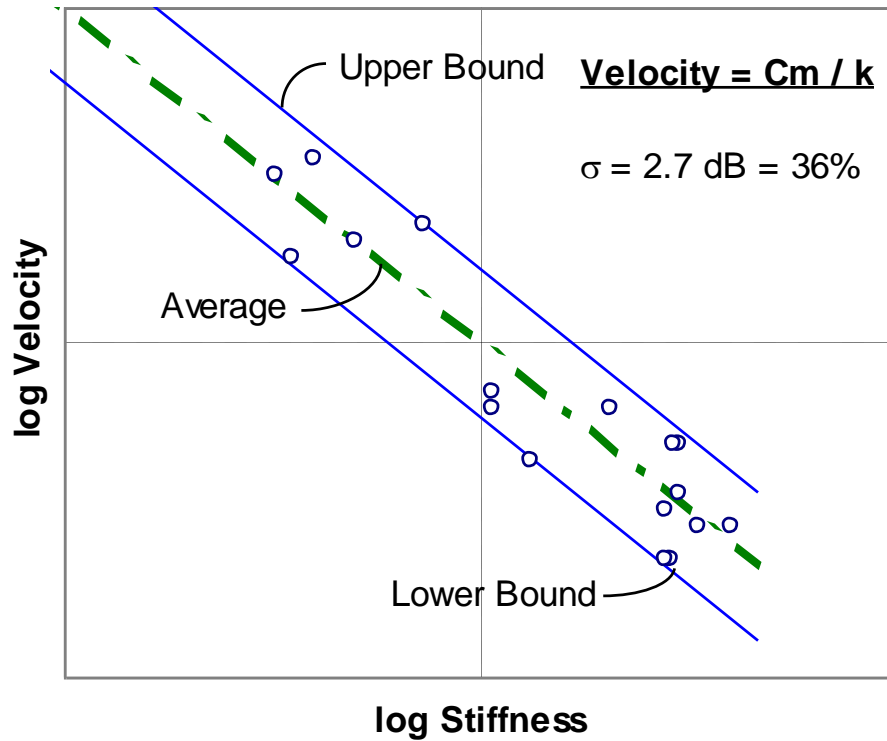
Penetrations

Separations (*aka* “Isolation Breaks”)

Raised Access Floors

“Mechanical” Model

(Vertical Vibration)

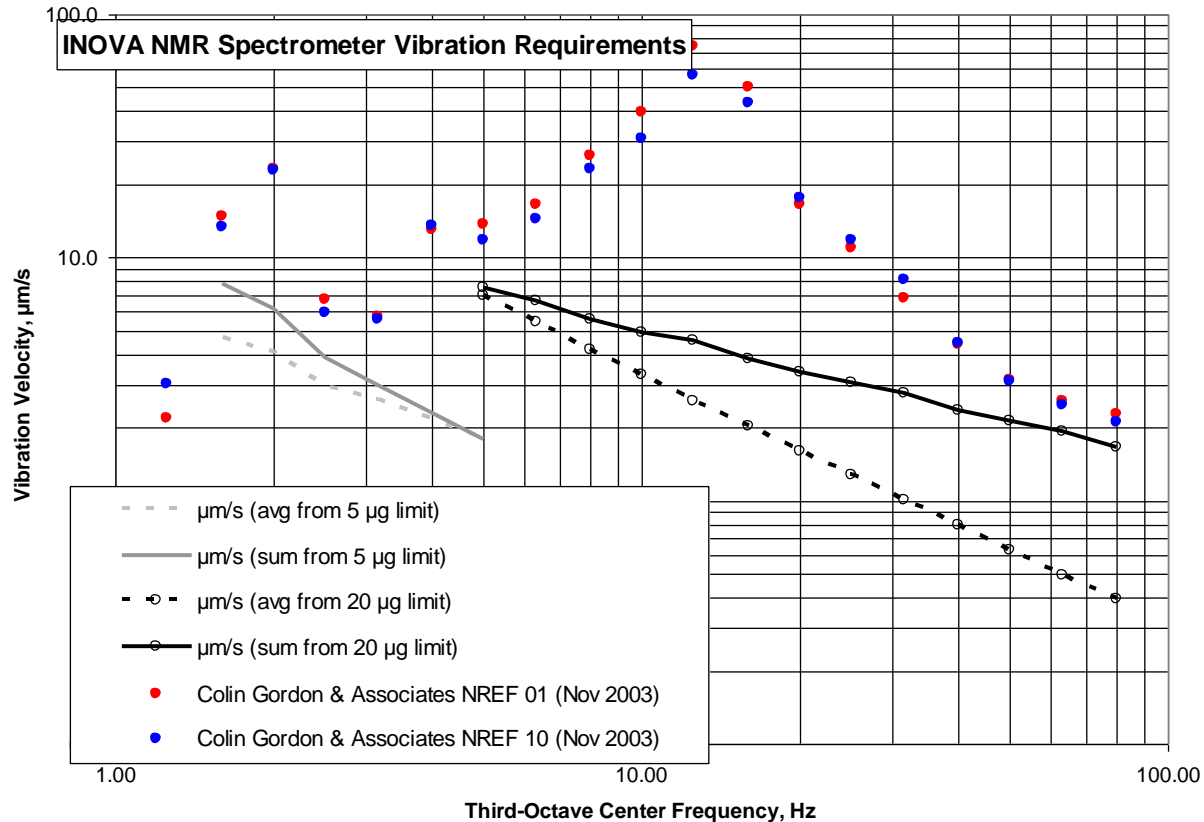


$$V_m = \frac{C_m}{k}$$

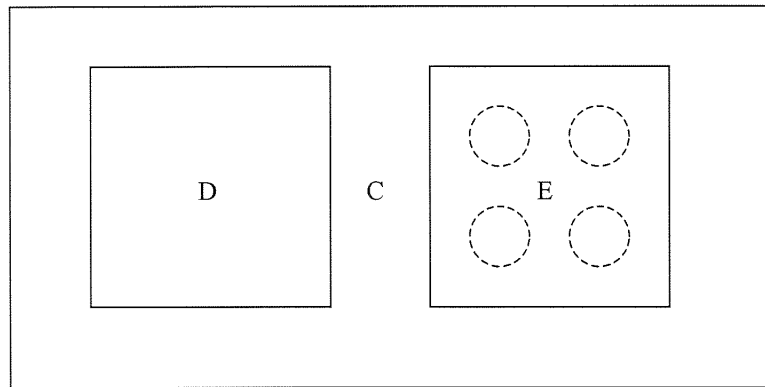
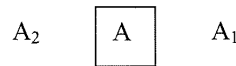
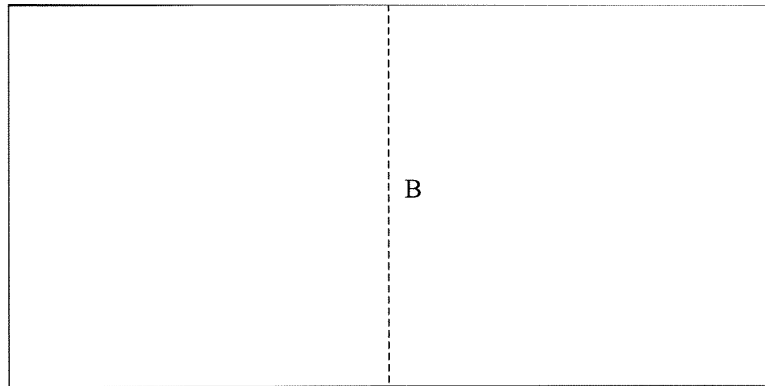
NINT Vibration Criteria

Space Category	Criterion (1/3-octave band)	Source
On-grade Characterization Labs	$3 \mu\text{m/s}$ at $f > 20 \text{ Hz}$ $0.025 \mu\text{m}$ at $f < 20 \text{ Hz}$	NIST-A
On-Grade Cleanrooms	$6 \mu\text{m/s}$	VC-D (IEST)
Level 2 Characterization Labs	$50 \mu\text{m/s}$	VC-A (IEST)
All other areas	$50 \mu\text{m/s}$	VC-A (IEST)
Ultra-sensitive space (future)	$0.75 \mu\text{m/s}$ at $f > 4 \text{ Hz}$	NIST-A1

NINT 2nd Floor NMR Site



Pile/Slab Study Experiment Layout



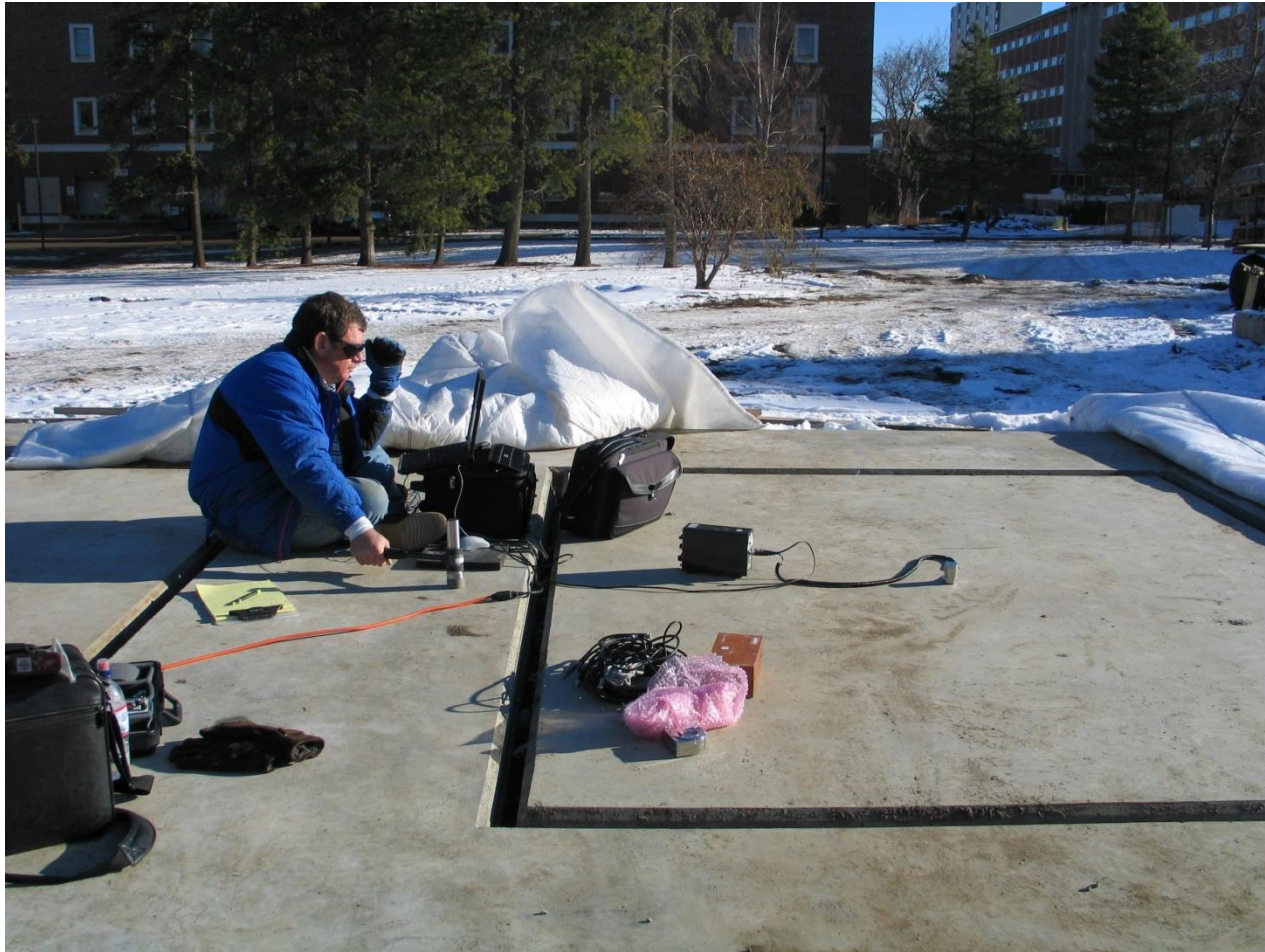
A = small slab
representing “free
field”

B = 8.85m x 3.85m x
300mm Slab

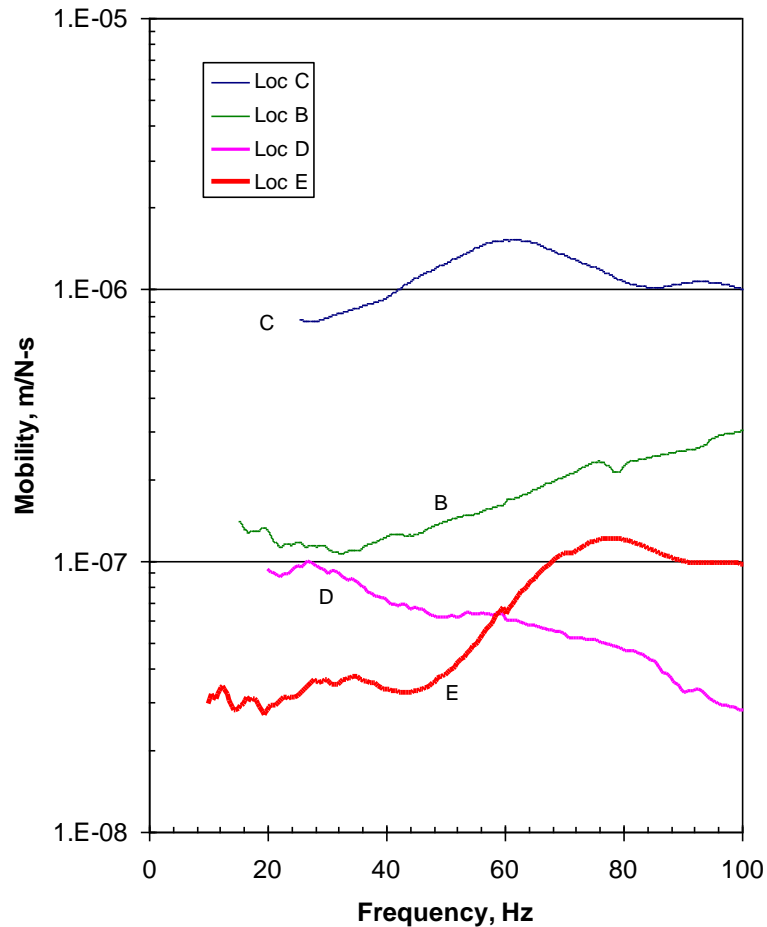
D = 3.0m x 2.5m x
900mm on 500mm
compacted fill

E = 3.0m x 2.5m x
900mm on 400mm
dia x 7.5m piles

Hammer Tests for Stiffness



Drive Point Mobility



Hammer tests to measure mobility (velocity divided by force)

Note “resonance” hump in E (mass on piles)

NINT Milestones

- Improving plastic solar cell performance.
- Pioneering the creation of single atom quantum dots.
- Developing the world's sharpest man-made object.
- Engineering the world's first single molecule electrical circuit.
- Attracting world-class talent.
- Collaborating with existing and future industry leaders.
- Opening state-of-the-art research spaces.
- Exploring innovative partnerships.
- Earning external recognition