

ENVIRONMENTAL NOISE AND GROUND VIBRATION CONTROL FOR PRECISION CALIBRATION LABORATORY

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A proposed precision calibration laboratory would require low continuous and transient ambient vibration and noise conditions to achieve consistent high-resolution and quality performance. The project location was to be adjacent to the firm's existing lab and manufacturing facility, and near a multiple-lane divided high-speed highway and a railroad. The owner manufactures precision pressure measuring and calibration instruments and systems. The expansion addition was intended to increase capabilities and capacity of the instrument calibration lab. A specialist was retained to consult with architects and engineers on design for control of floor vibration and ambient noise within the laboratory. Criteria from lab equipment manufacturers and from the consultant formed the basis for ground borne vibration and airborne noise site analyses; 1/3 octave RMS velocity and full (1/1) octave sound pressure spectra, both with 0-100 Hz frequency span amplitude limits. Pre-design on-site measurements were conducted for (a) exterior ground borne vibration, (b) airborne environmental noise measurements, (c) interior structure borne floor vibration and (d) laboratory airborne noise in the existing facility. Based on result-versus-criteria comparisons, design solutions were developed and recommended for the facility's architectural and engineering (structural, mechanical, electrical and plumbing) designs. Implementation of vibration and noise control concepts were limited to those which were complementary and compatible with conventional methods and materials of construction. Many of them were adopted by architects and engineers for integration into construction documentation. The case study will exhibit selected site and existing facility photos and measurement result noise and vibration spectrum charts for illustration. Success of project design will be presented based on post occupancy production quality and subjective owner's satisfaction.

Keywords: Environmental Noise, Ground Borne Vibration

1. Introduction

The Project Architects retained a vibration and noise consultant for a proposed precision Calibration Laboratory within a 4,180 m² (45,000 ft²) engineering and manufacturing building addition [1] for a firm that produces pressure calibration instruments used in calibration laboratories, manufacturing and field applications. The existing and proposed facilities are single-story buildings near a multi-lane divided high-speed highway and a railroad. The consultant's purpose was to determine acceptable limits of noise and vibration, and to estimate the sum of environmental plus internal source conditions in the building. Noise and vibration exceeding permissible criteria would require mitigation in the building design.

Calibration quality and resolution can be affected by structural (floor/foundation) vibration and airborne low frequency noise. Calibration equipment installations were to be designed for slab-on-grade floor, i.e., bearing directly on the soil or a compacted fill within an interior lab suite. Adjacent spaces in the building include offices, calibration lab storage/staging, information technology (IT) server room and employee amenities for workout, showers/lockers and toilet spaces. As a single story slab-on-grade building there is no basement nor any occupancy above the lab.

2. Proposed facility expansion/addition

The building site is adjacent to an existing manufacturing and lab facility (Fig. 1), located between a high-speed highway to the southeast and a local street to the northwest and a railroad main track line farther to the northwest, with freight trains nearly every hour. Highway vehicle traffic is the dominant continuous ground borne vibration source with secondary continuous contributions from surrounding facilities and outdoor mechanical equipment installations. Trains on the nearby rail and trucks at the shipping/receiving dock contribute transient vibration disturbances. External ground borne vibration from these sources may influence the labs' structural foundation vibration.

The proposed calibration lab suite is an interior location of the new building addition, as shown on the Fig. 1 floor plan. In addition to external vibration and noise, the labs will be subjected to internal building systems, manufacturing process and occupant activity vibration and noise. The internal sources include footfall impacts and rolling carts in nearby corridors, shop fabrication and manufacturing processes and building mechanical, electrical plumbing/piping and HVAC. If the aggregate sum of continuous and transient vibration exceeds permissible criteria, it could disturb calibration lab facilities or calibration procedures, resulting in out-of-tolerance or poor quality yield.



Figure 1: Site Plan: Existing building (left) and proposed manufacturing facility with calibration lab (right).

3. Acoustical and vibration design criteria

The calibration instrument manufacturer provided operational descriptions and subjective indications of acceptable vibration, but no specific or objective permissible vibration. The consultant recommended permissible noise and vibration design criteria for the precision calibration lab, based on the generic types of instruments, ancillary equipment and functions anticipated in the new facility with measurement of acceptable existing conditions to validate proposed criteria. The acoustical and vibration criteria would influence designs for structural foundation, architectural demising walls and ceiling, building systems, including HVAC, and support equipment, including air compressors.

3.1 Noise criteria

Continuous background or ambient noise Room Criteria (RC), as published in ASHRAE [2] and shown below, are octave band limits recommended for various functional areas. Airborne noise

criteria apply to continuous background noise due to building systems. The “A” and “B” zones of the low frequency airborne noise (upper left of level versus frequency chart) indicate levels of airborne low frequency noise capable of “acoustic coupling” or inducing vibration into light weight structures. Different criteria lines might apply to various functional spaces, but none of the spaces should permit continuous low frequency background noise in or above the “A” criterion zone. Similar commonly used Noise Criteria (NC, not shown here) were not recommended for the calibration lab rooms, because NCs do not express noise limits for the 16, 31.5 and 63 Hz octave bands.

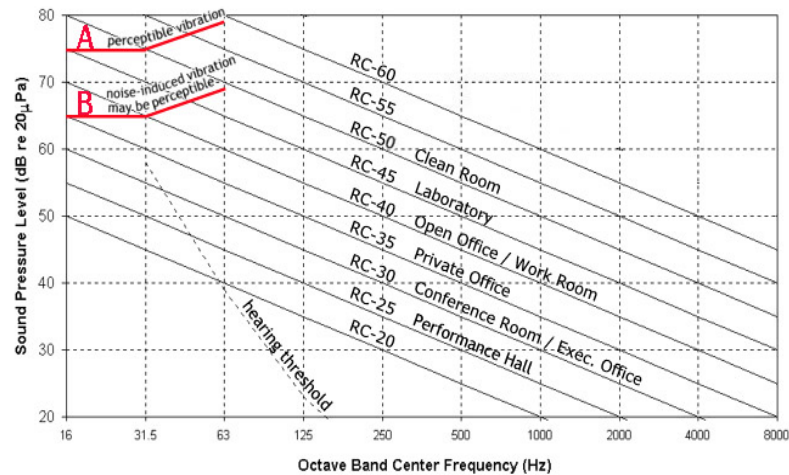


Figure 2: Room Criterion (RC) Curves. Note A & B regions of low frequency limits.

3.2 Vibration criteria

Generic vibration criteria (VC) [3,4] are often used in building programs for structural design to establish criteria for allowable building floor vibration spectra, in terms of one-third octave (constant percentage) bandwidth RMS vibration velocity levels. Vibration measurement results may be compared to the generic criteria for maximum floor velocity limits to determine need for and amount of mitigation required for the facility design phase.

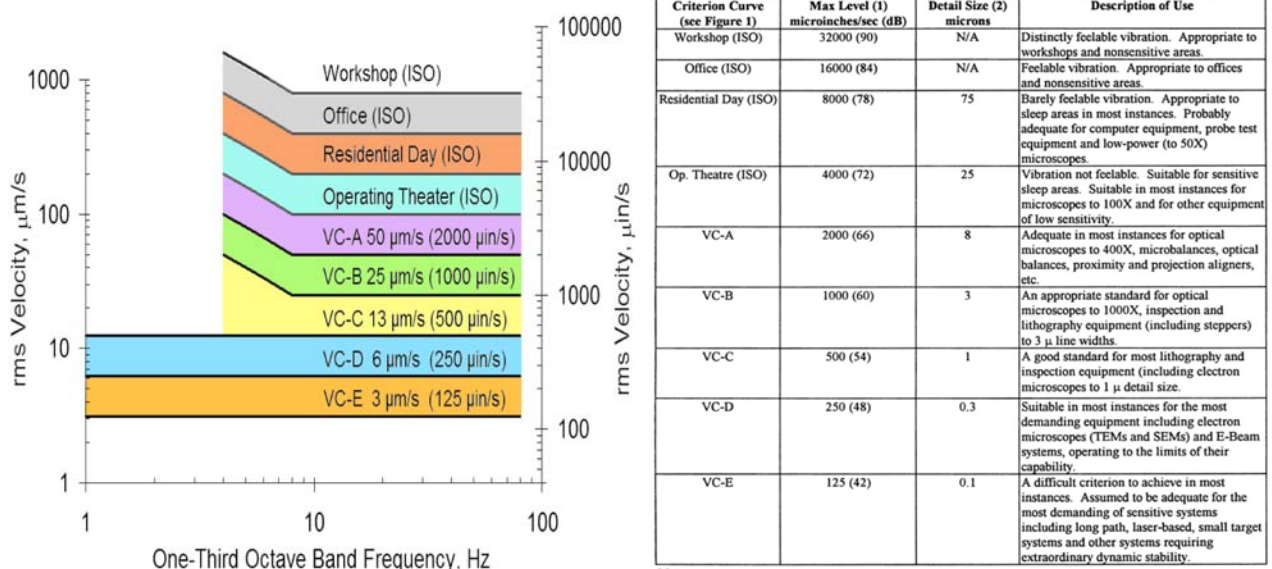


Figure 3: Generic Vibration Criterion (VC) Curves for 1/3 octave vertical floor RMS velocity vibration (left) with metric (micron/sec) values on left scale and Imperial (micro inch/sec) values on right scale.

The consultant recommended maximum permitted floor vibration criteria: VC-C, 12.5 μm/sec (500 μin/s) RMS velocity, with a preferred goal of VC-D, 6.25 μm/s (250 μin/s). Permissible low-frequency noise criteria, RC-region B, should be coordinated with vibration limits.

The manufacturer indicated that existing lab floors are acceptable when a nearby air compressor is not operating. The consultant would measure and compare interior floor vibration measurements in the existing lab to VC categories to validate the recommended criteria for the proposed lab.

4. Measurement locations, instrumentation and procedures

Observations and measurements of ambient and transient vibration and airborne noise were conducted during normal weekday business hours at the Calibration Lab's proposed location, within existing calibration labs and near outdoor air compressor equipment. Measurement of ambient ground spectra and levels can be compared with allowable vibration and noise criteria in regard to disturbance potential. Measurement of existing lab floor vibration and noise levels are intended for comparison with generic permissible floor vibration and airborne noise criteria to confirm site acceptability and assist in development structural and mechanical engineering design concepts.

4.1 Instrumentation

Airborne sound and ground or floor vibration measurement instruments included the following.

4.1.1 Airborne Sound

- Analyser: Larson Davis Laboratories (LDL) Model 824 Sound Level Meter, Real-Time Computing Spectrum Analyser, with Logging, S/N 1773, with LDL Microphone Model 2560, 1/2" (12.5 mm) random incidence (46 mV/Pa) ANSI Type I re (+/- 1 dB) precision microphone, S/N 3261 and Preamp: PRM902, S/N 2288
- Sound Calibrator: LDL Model CAL200, 94 dB @ 1k Hz, S/N 3352 (current certification).

4.1.2 Ground and structure borne vibration

- Vibration analyser: Larson Davis Labs Model 2900, Two-Channel, Fast Fourier Transform (FFT), Portable, Real-Time Computing Spectrum Analyser, S/N 0145.
- Measurement Accelerometers (2): Wilcoxon Research Model WR 731A "Seismic" Acceleration Transducers (10 V/g), S/N 1230 and 2140, sensitive to motion along one axis.
- Calibration: PCB # 394M26 Exciter, S/N 1293 (1 g @ 160 Hz) with reference transducer WR 726 Accelerometer (100 mV/g), S/N 3431, sensitive to motion along one axis.

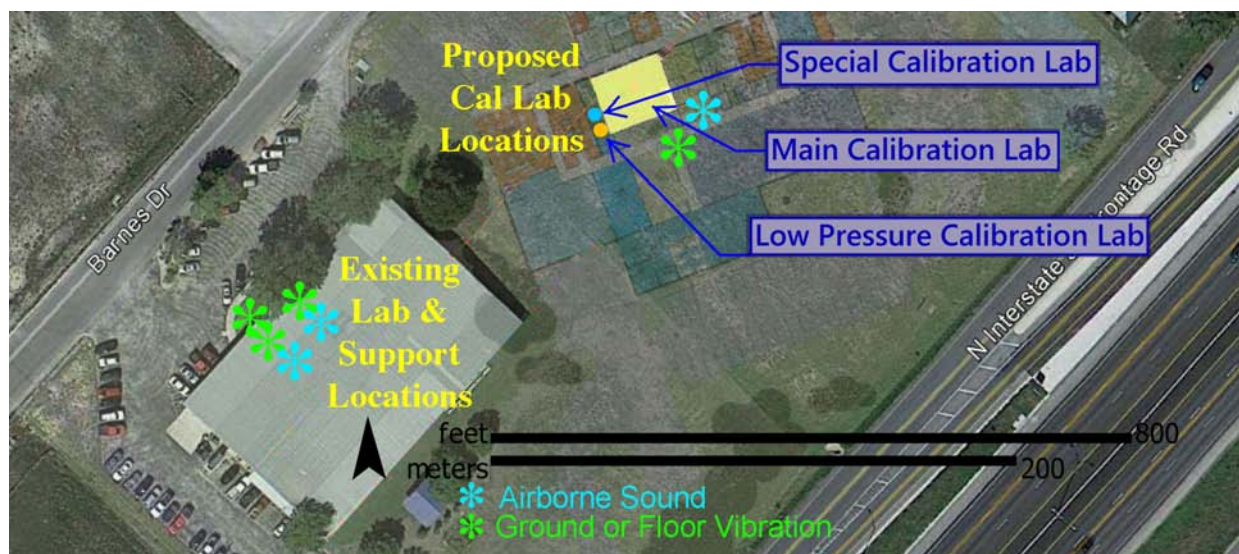


Figure 4: Calibration facility site aerial view with existing building and proposed lab plan superimposed.

4.2 Measurement locations

The proposed lab site (outdoor) measurement locations are shown on the Fig 4 aerial view. Outdoor and indoor vibration measurement locations are pictured in Fig. 5; a-d. Airborne sound was

also measured at each vibration measurement location. The air compressor is an exterior location immediately adjacent to the labs' exterior building wall.

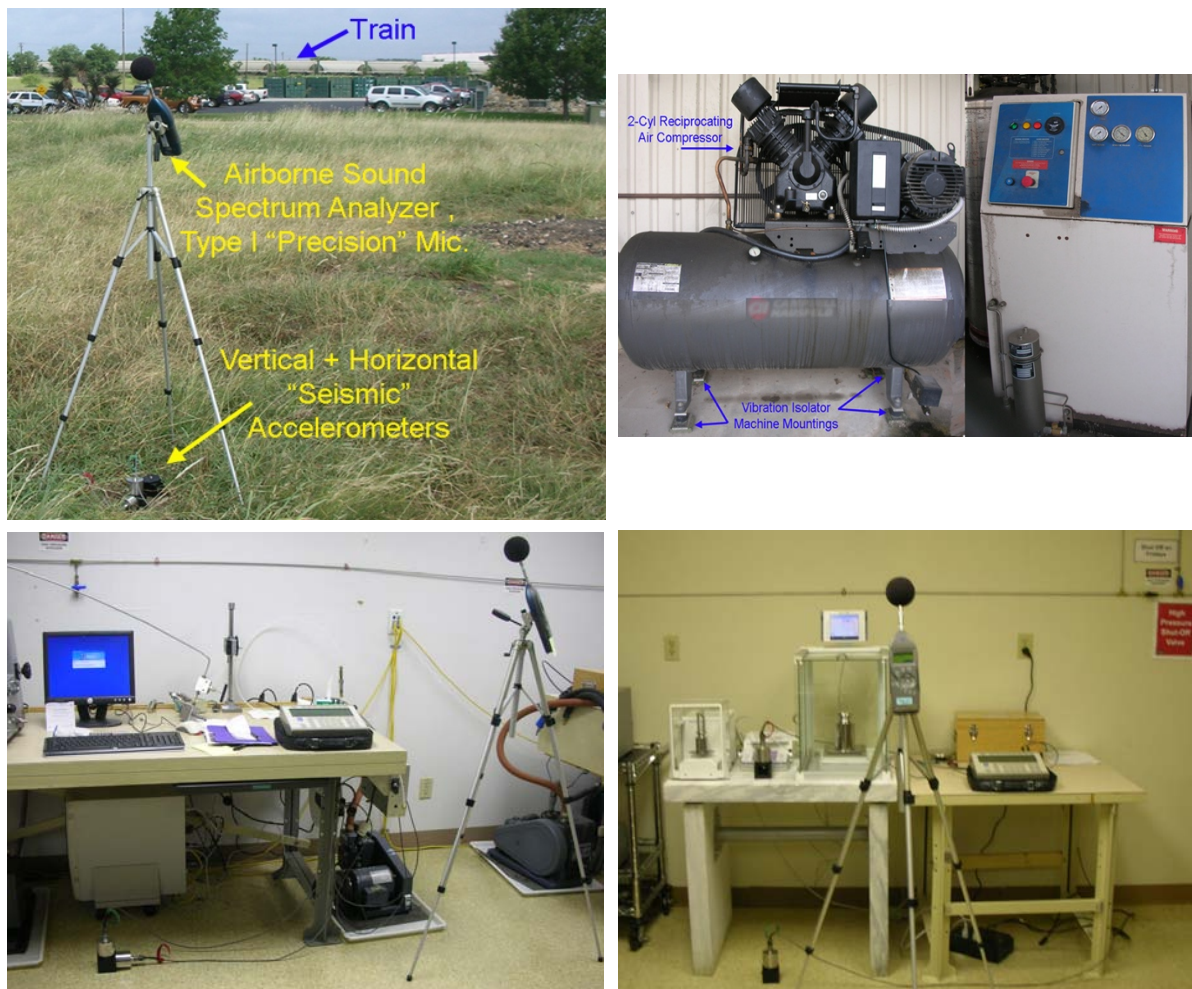


Figure 5 a-d : Measurement locations: Proposed site to north east (top left), (b) compressor equipment, disturbance source, (c) existing Calibration Lab and (d) existing Mass Compare Lab (bottom right).

4.3 Measurement procedures

At each existing and future lab location, vibration measurements were taken in vertical and in horizontal directions, outdoors on the ground and indoors on the floor, respectively. Airborne noise measurements were obtained with a spectrum analyser on a tripod at approximately 5' (1.5 m) above ground or floor elevation at each vibration location and near the exterior air compressor.

Narrow (constant) bandwidth ambient and transient vibration levels were directly measured from 0.2 Hz up to 156 Hz, sampling for at least 120 seconds, and sometimes up to 180 seconds. 1/3 octave (constant percentage) bandwidth vibration was measured in 1 Hz–315 Hz bands. Transducers on mass bases were placed on soil for ground borne measurements. Petroleum-based wax was used to make positive contact between the seismic transducer base and the floor for structure borne. Acceleration data was acquired in dB re: 1 g RMS. All results were stored on-site in the LDL-2900 non-volatile memory for analysis and downloading offsite in the consultant's offices.

Measurements were conducted in two directions at a time. Where three axes are evaluated at a single location, they are not simultaneous. The vertical and horizontal data, not being simultaneous, may be influenced by transients, but are intended to be representative of actual conditions. Comparison of any one location to another necessarily involves time related variations particularly, for short-duration transient (L_{max}) results. Integration of multiple samples in equivalent level (L_{eq}) results tends to average down transients, resulting in indications of typical continuous conditions.

Measurement results may be reliably compared to other standards, criteria, or data only if metrics are similar, including terms (acceleration, velocity, displacement), time spans (2, 4, 16, 60 sec., etc.) bandwidth (1/3 octave, 0.5 Hz, 1 Hz, etc.), axis (vertical or horizontal), and peak span (0 - peak, peak to peak, or RMS). Metrics and terms may be converted, but all terms for any given sets of comparative data must be compatible for all parameters listed herein. Where vibration levels are expressed in linear terms, such as dB re: 1 g (1 g = 0 dB, 1 μ g = (-)120 dB), each logarithmic order of magnitude, 0.01 to 0.1, etc., is equivalent to 20 dB.

5. Measurement results and findings

5.1 Measurement results

Ambient and transient vibration amplitude results were graphed on level vs. frequency charts, re: Fig. 6. Narrow band charts exhibit prominent discrete frequencies of vibration, while 1/3 octave charts show levels or amplitudes and are compared to VC categories (VC-C permissible in labs).

Ground borne vibration measurements indicate dominant frequencies in the ground at 6 Hz and 9 Hz, plus harmonics (multiples) at 18 Hz and 25 Hz. Levels are suppressed at 13 Hz and 22 Hz. Prominent frequencies of vibration generally indicate natural or fundamental resonant frequencies and/or their harmonics (multiples, i.e., if 7 Hz is fundamental, 14, 21, 28, etc. are harmonics).

Statistical percentile (Ln) spectra were also graphed for indications of difference between continuous and variable transient levels (not shown here). L90 is the nearly continuous threshold level 90% of the time. The median, 50% level, is L50. The transient level only occurring 1% of the measurement period is L1. Where there are large gaps between L90 and L1, the level is variable. Where all of the Ln spectra bunch up at any given frequency, there is indication of tonal condition.

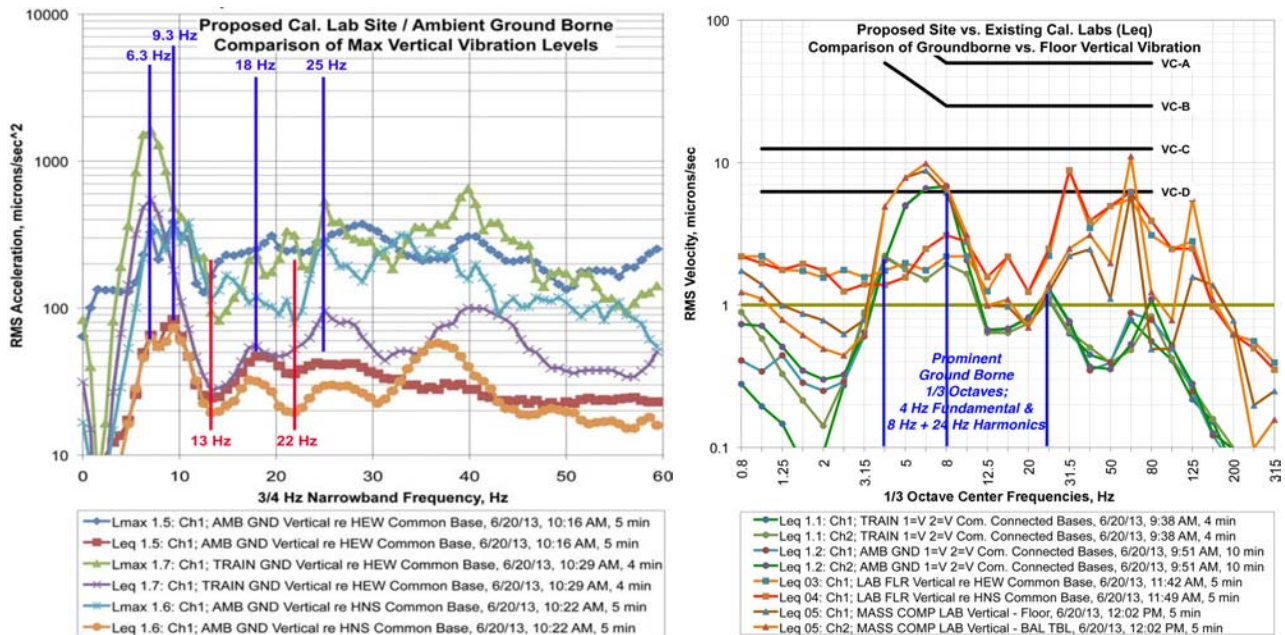


Figure 6 a, b : Narrow (constant) bandwidth vertical vibration with prominent frequencies annotated (left) and 1/3 octave (constant percentage) bandwidth vertical vibration chart with prominent bands annotated (rt)

5.2 Findings [5]

1. The existing laboratory is acceptable for current calibration procedures, except when the nearby air compressor is operating; indicating desired vibration acceptability guidance.
2. Outdoor ambient sound levels are variable, and range from 55 dBA/61 dBC to 75 dBA/87 dBC. The L33 (level 1/3 of the time) is 63 dBA/73 dBC. Outdoor to indoor sound transmission loss

via the building shell is based on these levels with consideration given to low frequency sound intrusion to sensitive spaces.

3. Interior sound levels within the existing calibration labs range from low of 60 dBA/67 dBC to 70 dBA/87 dBC. The L33 is 62 dBA/70 dBC. Low frequency bands, 16 Hz and 31.5 Hz, exceed 70 dB up to 33% of the time. This airborne noise disturbance, in concert with floor vibration that cause calibration procedure difficulty indicate low frequency limitations needed for new facility design.

4. Ground borne and floor slab vibration spectra show elevated levels in 4 Hz–8 Hz 1/3 octaves. The existing building floor vibrations show significant peaks in 31.5, Hz, 63 Hz and 125 Hz bands. Structural designs should avoid 4-8 Hz resonances, but 10-14 Hz natural frequencies are desirable.

5. The existing labs exhibit several discrete frequency tones that are due to building occupancy, equipment or other internal sources. 1/3 octave measurements show significant peak levels in 31.5, 63 and 125 Hz bands, which may be governed or at least heavily influenced by nearby outdoor air compressor. Horizontal direction vibrations, including peak bands, conform to permissible criteria.

6. Floor vibration in existing Mass Compare lab and Calibration Labs vary somewhat, but transient disturbance amplitudes are similar to ground borne disturbance near the outdoor compressor.

6. Noise and vibration design recommendations [6]

Architectural layout and demising assembly designs plus building system and lab support systems noise and vibration control recommendations were presented for the fit-out improvements.

6.1 Architectural layout

Architectural layout recommendations were presented to increase distance between proposed lab spaces and impact or vibration sources by moving sensitive labs away from nearby vibration source spaces, as illustrated in Fig. 7. Footfall, rolling carts or trollies in the corridor and the employee workout room are potential sources of impacts and transient vibrations. The IT/Server space nearby could be a source of mechanical vibrations, including computer room air conditioner (CRAC) units.

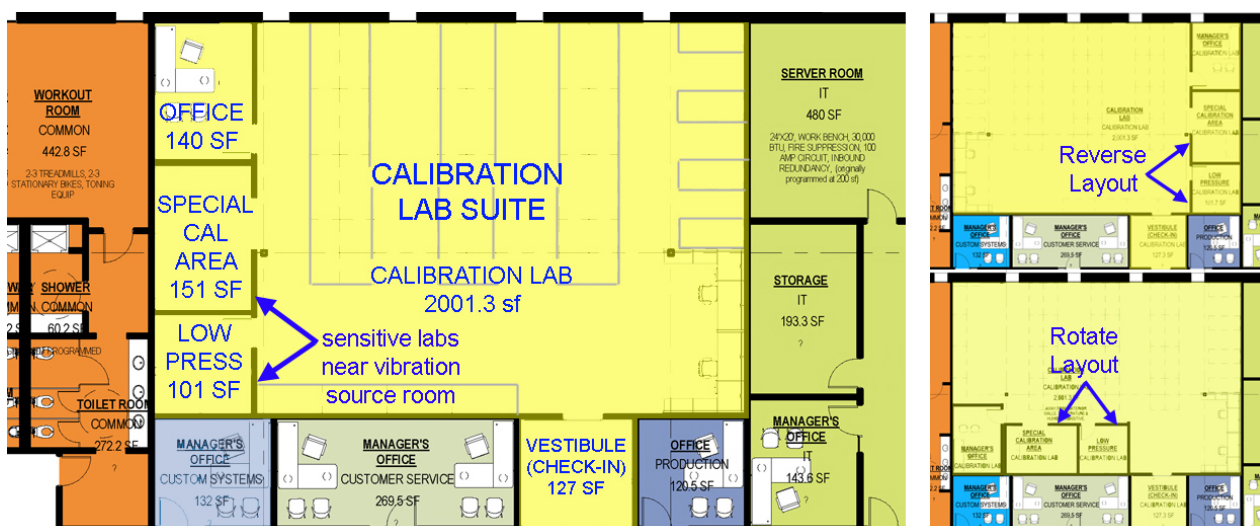


Figure 7 : Calibration Lab Suite with surrounding spaces and Alternate Layouts

- Decouple demising partition framing with resilient channels or similar drywall mountings to reduce structure borne vibration transmission and radiated noise
- Suspend lab ceilings on resilient mountings to reduce vibration and related air pressure pulsation or fluctuation, or self-support ceiling structure to decouple from building structure.
- Coordinate building systems layout to avoid vibration and noise sources in lab envelope.
- Specify acoustically absorptive wall and ceiling materials to reduce reverberant build-up.

6.2 Structural design

- Calibration and Mass-Compare Lab floors should be decoupled from building floor using 13-25 mm ($\frac{1}{2}$ -1 inches) structural isolation break (SIB, with resilient filler) to reduce lateral transmission of floor impacts and vibration into the calibration labs. No rigid rebar, pipe, conduit, etc. should be permitted to cross or “bridge” the joint.
- In addition to SIB, provide 6” (150 mm) compacted sand fill between engineered sub-soil fill and slab for an impedance mismatch to reflect and refract ground vibration under slab.

6.3 Building systems / mechanical, electrical, plumbing, HVAC design

- MEP designs should respect the vibration isolation perimeter around calibration lab by designing/specifying flexible couplings for any pipes, conduits or ducts that are routed into or through the lab spaces, whether in partitions or in ceiling plenum above labs.
- HVAC design should not locate mechanical equipment above the calibration labs, either in the ceiling plenum or on the roof. Vibration isolation effective down to very low frequencies (i.e., high static deflection isolators) should be specified for any roof-mounted or suspended mechanical equipment within one structural bay of calibration labs.
- Air handler, exhaust, air terminals and other equipment/systems should be designed for combined additive sources not to exceed RC-35 in the labs, or slightly greater if no 16, 31.5 and/or 63 Hz octaves exceed RC Zone-B, 65 dB, in lab spaces. Also avoid tonality of sound, i.e., individual octave or 1/3 octave bands exceeding sidebands by more than 5 dB.
- Equipment vibration isolation should be designed and specified in general accordance with ASHRAE 2011 Applications, Chapter 48, Table 47 with related notes (previously referenced).
- Do not specify or install rotary helical or screw compressors for air or refrigeration unless located remotely outside on separate foundation with flexible couplings for all attachments.

7. Implementation and results

The new laboratory design was completed with vibration and noise recommendations integrated into architectural and engineering construction documentation drawings and specifications. Construction generally conformed to the design intent as implemented in construction documentation.

The owner/occupants subjectively indicated successful post-occupancy laboratory operations. No complaints or consultant call-backs for adjustments or modifications have been necessary.

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REFERENCES

- 1 Architect’s facility description [online] : <http://www.gsearchitects.com/GSCwork/mensor>
- 2 ASHRAE *Handbook of HVAC Applications* “Sound and Vibration Control,” Chap. 48, Table 1, Chart 6, American Society of Heating Refrigerating and Air-Conditioning Engineers, Inc., Atlanta (2011)
- 3 Institute of Environmental Sciences (IEST), *Recommended Practice RP-012*, App. C, IES-RP-CC012.2, Institute of Environmental Sciences, Rolling Meadows, IL, USA (2005)
- 4 *Ibid.*, ASHRAE *Handbook of HVAC Applications*, Chap. 48, Table 41, Chart 41 (2011)
- 5 Evans, J. B., *Ground Borne & Floor Vibration and Noise Measurement Results - Vibration and Noise Control Conceptual Recommendations*, Unpublished consultation report to GSC Architects, (5/2013).
- 6 *Ibid.*, consultation report