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*Final Report*

# VIBRATION ASSESSMENT OF CRITICAL IMAGING SPACES FOR THE NEW PARKLAND HOSPITAL

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## ABSTRACT

The Parkland Health and Hospital System (PHHS) is nearing substantial completion of The New Parkland Hospital and has requested a preliminary vibration survey be conducted in 17 vibration sensitive medical imager rooms and one corridor that passes over three operating rooms. Vibration data are acquired simultaneously in three orthogonal directions (north, east, up) in each space and are evaluated relative to the vibration specifications associated with the imaging equipment scheduled for each space. Structural dynamics analyses are performed to determine the effect of the 12-in-thick topping slab and equipment mass that are not present and the effect of wind-induced sway motion for the imager located on the 16$^{th}$ floor of the Acute Tower. All of the spaces tested satisfy the vibration requirements with significant margin in most cases. The vibration isolation system for the 16$^{th}$-floor imager is not essential given the very low probability that wind-induced sway motion will adversely affect that imager's performance.

**KEYWORDS:** Ground-Borne Vibration
Floor Vibration Testing
Vibration Sensitive Equipment
Wind-Induced Vibration

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## EXECUTIVE SUMMARY

Construction of The New Parkland Hospital is nearing completion and the Parkland Health and Hospital System (PHHS) requested that a vibration survey be performed in 18 vibration-sensitive spaces before installing the imaging equipment in those rooms. Ten (10) of the imaging rooms will house Magnetic Resonance Imagers (MRIs) and Dual- and Single-Source Computed Tomography (CT) imagers manufactured by Siemens Healthcare and have specific vibration requirements expressed in the form of a frequency-dependent acceleration limit. Seven (7) of the rooms identified by PHHS contain various imaging equipment that merely require a "typical clinical environment." The vibration requirement for operating rooms defined by the International Standards Organization (ISO) is used for these rooms. The final "room" is a corridor that passes over one end of three operating rooms and the ISO operating room vibration limit of 4000 μin/sec is used for this space as well.

The vibration survey was conducted on January 7 and 10, 2014. Vibration data are acquired simultaneously in the north, east, and up directions in each of the 18 spaces identified by PHHS. Many of the building's mechanical systems are in place and are operating. Ground-borne vibration from vehicular traffic on surrounding roadways, on the jobsite, and a nearby Dallas Area Rapid Transit light rail track also contribute to the vibration within the building. Construction workers are responsible for human-induced vibration that ranges from representative hospital operational vibration to very high, non-representative vibration. In the more extreme cases, BARA floor construction managers were requested to temporarily stop construction activity in some rooms to permit more representative vibration measurements. For the most part, the vibration environment present during the vibration survey represents or exceeds normal hospital operation.

Many of the critical imaging spaces are designed to accommodate a 12-in-thick topping slab poured on top of the reinforced concrete pan joist floor system. The topping slab is present in some, but not all, of the spaces. The addition of the topping slab and equipment will alter the vibration characteristics of the floor. One of the CT imagers will be located on the 16$^{th}$ floor of the Acute Tower where wind-induced sway motion may affect its operation. Structural dynamics analyses are performed to evaluate the effects of the topping slab, equipment weight, and building sway motion. The addition of the equipment to a finished room will tend to increase the vibration by a factor of 1.5 to 2.0 near the floor's modified resonance frequency. The vibration performance of rooms without the topping slab is expected to be improved when the topping slab and the equipment are added. Wind-induced sway motion can exceed the transient vibration limit of the CT imager; however, the probability of gust wind speeds greater than 75 mph occurring when the imager is in use is extremely low.

The imaging spaces identified by PHHS for the vibration survey satisfy all of the documented or adopted vibration criteria. The current vibration level in the MRI spaces is about 1/10 of the limit. The measured vibration in the other imager spaces is about 1/100 of the limit. Walking-induced vibration of the corridor over the operating rooms has little effect; however, ambient vibration levels are about 1/8 of that limit. The vibration performance of the imaging spaces is very good and equipment installation should proceed as planned. PHHS may wish to consider whether the vibration isolation system for the 16$^{th}$-floor CT imager is necessary given the very low probability that high winds will interfere with the imager's performance. Finally, PHHS should also consider a limited follow-up vibration survey once the MRIs and remaining mechanical systems are installed.

# Section 1

## BACKGROUND

The New Parkland Hospital is located in Dallas, Texas north of the intersection of Harry Hines Blvd. and Medical District Dr. An overhead rendering of the site and a recent construction photograph (looking north) are shown in Figure 1-1. Harry Hines Blvd. is a 6-lane roadway and Medical District Dr. is a 4-lane roadway; however, traffic lights on both streets maintain a relatively slow (30 mph) vehicle flow rate. The Central Utilities Plant and a Dallas Area Rapid Transit (DART) light rail track and terminal are located just to the north of the site. The main complex consists of the 17-story Acute Tower, the intersecting 9-story WISH Tower, and a 4-story Podium structure.

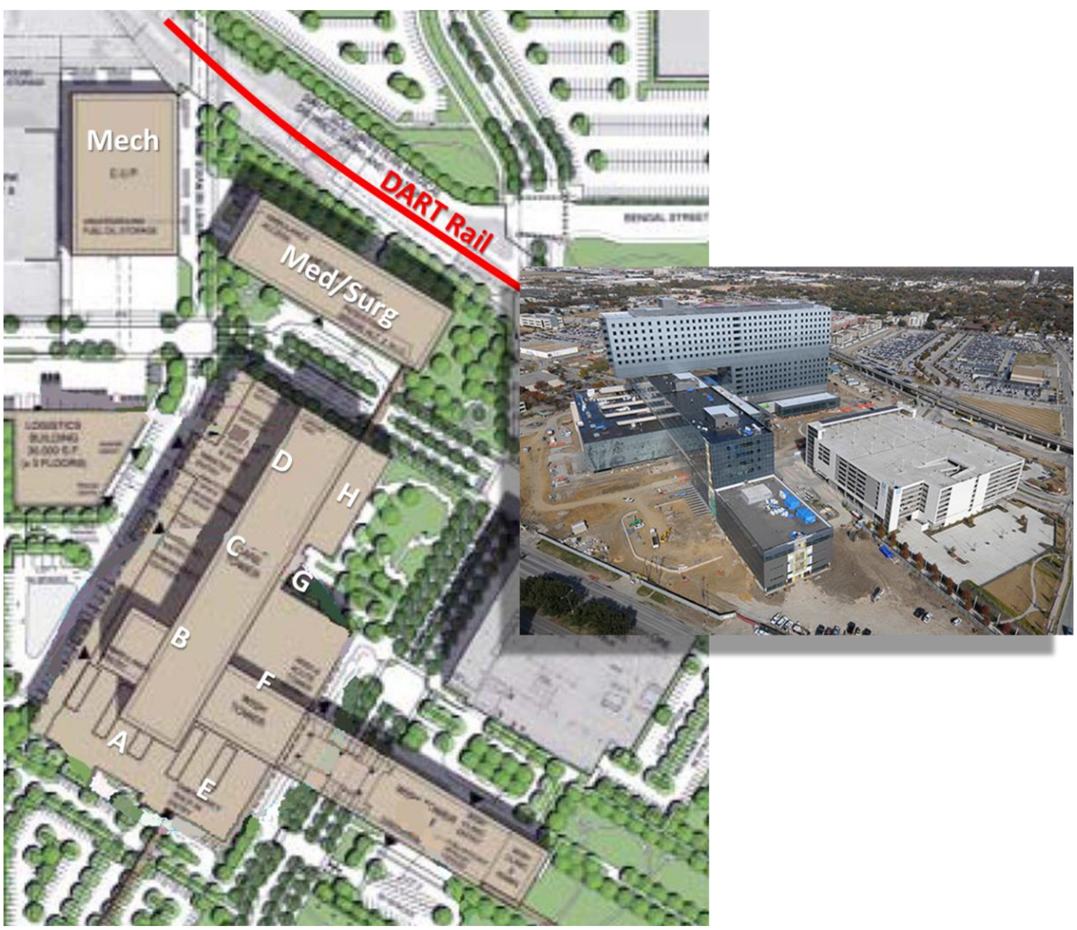



**Figure 1-1 The New Parkland Hospital Site and Room Section Key Plan.**

The main complex of The New Parkland Hospital is complete as far as the primary structural framing, exterior envelope, and most of the non-load-bearing metal stud walls are concerned and is scheduled to be commissioned in the latter half of 2014 or early in 2015. Medical equipment are not installed; however, the Parkland Health and Hospital System (PHHS) requested that the vibration environment in the most critical imaging spaces be measured and compared with the corresponding equipment specifications for those spaces before the final finish-out and equipment installation. Structural Engenuity, Inc. (SEI) is engaged to perform the on-site vibration survey and to provide an evaluation of the imaging spaces identified by PHHS.

## 1.1 ROOMS IDENTIFIED FOR VIBRATION ASSESSMENT

PHHS identified 18 rooms for this vibration measurement and assessment task. The room numbers (preceded by the building section letter), the equipment scheduled for those rooms, and the corresponding equipment vibration requirements are summarized in Table 1-1. Letters A through H are superimposed on the main complex in Figure 1-1 that correspond to different sections within the complex. The majority of the 17-story Acute Tower falls in Sections B, C, and D. Sections A and E contain most of the imaging spaces. The various sensitive medical equipment are primarily manufactured by Siemens Healthcare and include Magnetic Resonance Imagers (MRIs), Dual-Source and Single-Source Computed Tomography (CT) imagers, Positron Emission Tomography/Computed Tomography (PET/CT) molecular imagers, and Single-Proton Emission Computed Tomography (SPECT/CT) imagers. The last “room” listed in Table 1-1 is a corridor that passes over one end of several operating rooms on the floor below. The vibration requirements for this space are obtained from the General Notes section of the Contract Documents.

**Table 1-1 Vibration Assessment Locations, Equipment, and Specifications.**

| Imaging Rooms | Equipment | Specification |
|---|---|---|
| E2122, E2124, E2129, E4193 | Magnetom Skyra 3.0T and Aera 1.5T MRI | Ref. [1], Ref. [2] |
| E2101, A1186 | Somatom Definition Flash CT | Ref. [3] |
| D16119, E2102, A2191, A1188 | Somatom Definition AS64 CT | Ref. [4] |
| A2103, A2139, A2142, A2144, A2147, A2149, A2152 | Misc. PET/CT and SPECT/CT | Ref. [5]—Ref. [8] |
| C4C01 (corridor) | Operating Room (below) | Ref. [9] |

There is ongoing construction within and around the rooms identified in Table 1-1. The current construction effort is focused on finishing out walls and floors, placing electrical wiring, and pouring topping slabs in some imaging spaces. Construction-induced vibration is present and, in many cases, exceeds the vibration expected during normal hospital operations. The construction manager, BARA, was very helpful in limiting construction activities in and around those rooms where vibration data were being acquired. The MRI room on the fourth floor, E4193, is across a corridor from a large mechanical room. Some of the equipment is in place and operating, however, two suction pumps slated for the room are present, but are not installed. Air handling units distributed around the complex are operating.

## 1.2 VIBRATION CRITERIA

The vibration criteria provided in Ref. [1] through Ref. [4] for the Siemens MRIs and CT imagers are expressed in the form of narrowband acceleration spectra and are plotted in Figure 1-2. The maximum-allowed root-mean-square (RMS) acceleration determined over the specified bandwidth is provided as a function of the narrowband center frequency. The vibration specifications for the Siemens Somatom Definition Flash (Ref. [3]) and AS64 (Ref. [4]) clearly define the bandwidth to be 1 Hz. The specifications for the Skyra 3.0T (Ref. [1]) and Aera 1.5T (Ref. [2]) are identical but neither document explicitly identifies the bandwidth that should be used. Additional documentation obtained from Siemens failed to resolve this issue. It is reasonable to assume that Siemens employs the same bandwidth for the MRI vibration specifications as the CT specifications; hence, the 1-Hz bandwidth is used for the two MRIs as well.

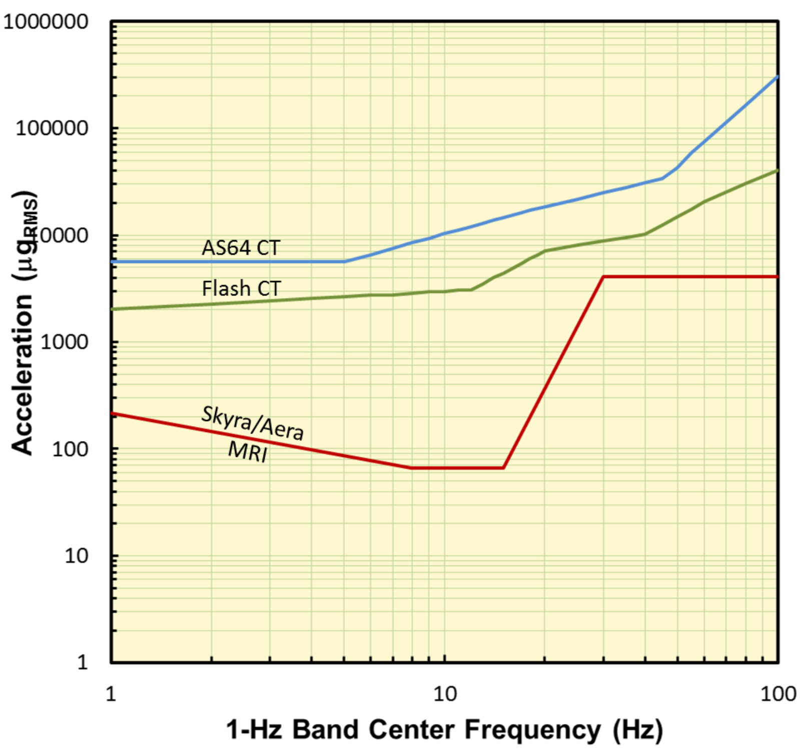



**Figure 1-2 Siemens Narrow-Band (1 Hz) MRI and CT Vibration Criteria.**

The vibration specifications provided in Ref. [5] through Ref. [8] do not contain explicit quantitative vibration limits, but do call for a "vibration free location as found in a typical clinical environment." The International Standards Organization (ISO) defined a baseline vibration criterion (Ref. [10]) that is currently used for operating rooms. Generic vibration criteria (VC) have since been established (Ref. [11]) relative to the ISO criterion for evaluating spaces intended to support vibration-sensitive equipment. These criteria are defined using the 1/3-octave proportional bandwidth rather than the constant bandwidth Siemens employs for its MRIs and CT imagers and are plotted in Figure 1-3. A proportional bandwidth varies with its center frequency. At 1 Hz, the measured vibration is combined over a 1.23-Hz band, at a 10-Hz center frequency, this bandwidth increases to 12.3 Hz, and at 100 Hz, the bandwidth is 123 Hz. For the purposes of this evaluation, a "typical clinical environment" is conservatively assumed to be represented by the ISO-defined criterion for an operating room.

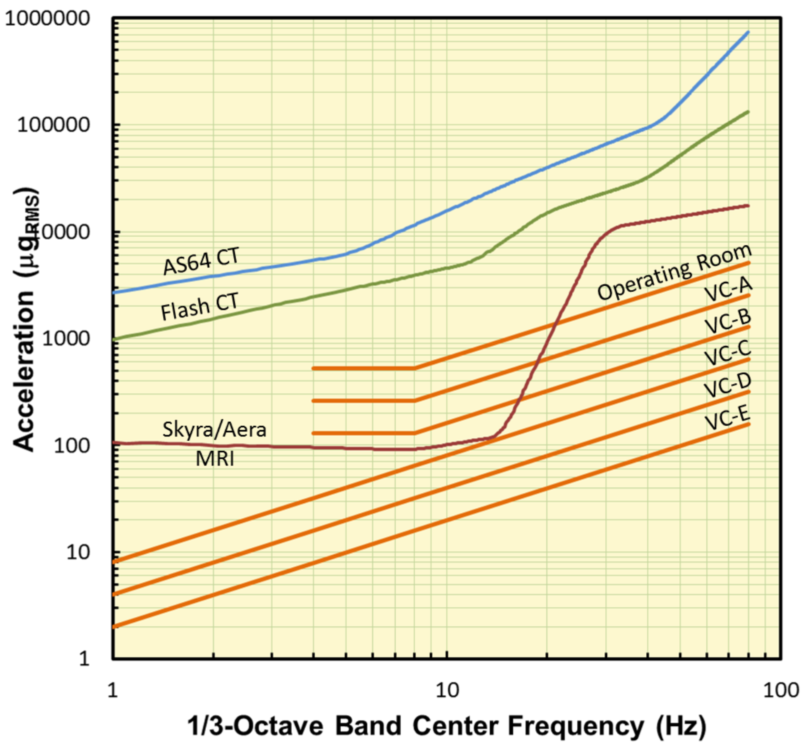



**Figure 1-3 Comparison of Siemens MRI and CT with the Generic Equipment Vibration Criteria.**

Narrowband vibration specifications can be converted into the 1/3-octave proportional band format for comparison. The Siemens MRI and CT imager vibration specifications shown in Figure 1-2 are plotted in Figure 1-3 for comparison with the ISO and VC curves. The VC-C curve is traditionally associated with MRIs and the Skyra and Aera MRI specifications do in fact dip down to the VC-C level at a 15 Hz center frequency, which tends to validate the use of 1 Hz for the narrowband specification. The AS64 and Flash CT imagers are much less sensitive to vibration than a typical operating room. For all practical intents and purposes, the CT imagers are not classified as vibration sensitive equipment.

The MRIs are about 50 times more sensitive to vibration in the critical 8 to 15-Hz band than are the CT imagers. Imager sensitivity to vibration decreases with increasing vibration frequency; however, structural modes of vibration (floor system and column "pogo" modes) tend to fall in the 10 to 50 Hz range, depending upon the specific form of construction. Pedestrian-induced vibration occurs in the 1 to 3-Hz band. Ground-borne vibration from vehicular traffic tends to reside in the 8 to 15-Hz region and building mechanical systems introduce very narrowband structure-borne vibration within the 20 to 40-Hz range. Hence, the high-sensitivity band (8 to 15 Hz) for the MRIs occurs where various sources of vibration can be magnified by the structure.

The final space of interest identified in Table 1-1 is the corridor that passes over three operating rooms. The General Notes, Ref. [9], require that the corridor floor (the operating room ceiling) vibration not exceed 4000 μin/sec for one person walking at 100 steps/minute. This requirement corresponds to the ISO operating room curve shown in Figure 1-3. At 8 Hz, the maximum-allowed acceleration is 500 $\mu g_{RMS}$ and at 80 Hz, the maximum-allowed acceleration is 5000 $\mu g_{RMS}$. These acceleration limits are converted into the corresponding RMS velocity limit per

$$v_{\max} = \frac{a}{\omega} = \frac{(500\ \mu g_{\text{RMS}})(386.1\,\text{in/s}^2)}{2\pi(8\,\text{Hz})} = \frac{(5000\ \mu g_{\text{RMS}})(386.1\,\text{in/s}^2)}{2\pi(80\,\text{Hz})} = 3840\ \mu\text{in/s} \tag{1}$$

which agrees with the 4000 μin/sec requirement defined in Ref. [9]. Hence, the ISO operating room criterion is also used to assess the vibration of the corridor floor in response to one person walking at 100 steps/min.

# Section 2

## FLOOR SYSTEM AND LATERAL VIBRATION ANALYSIS

The vibration measured in the building includes the contribution of the DART light rail and vehicular traffic, some pedestrian traffic (construction workers), and those mechanical systems that are installed and operating in the building. Most of the imaging spaces are designed with a 12-in. recess that will be filled with concrete before the equipment are installed. At the time of the site visit, most of the recessed spaces remain and no equipment are present. One CT imager is located on the 16th floor of the Acute Tower where wind-induced vibration of the tower will contribute significantly to the acceleration environment; however, at the time the measurements were obtained, there was no significant wind. The structural dynamics effects of the added topping, the equipment weight, and high winds must be accounted for via analysis.

### 2.1 FLOOR VIBRATION—EFFECT OF TOPPING SLAB AND EQUIPMENT WEIGHT

Adding concrete topping to the existing floor system increases the mass and stiffness of the floor. If the mass increases at a greater the rate than the stiffness increases, the fundamental resonance frequency of the floor tends to decrease. On the other hand, if the floor stiffness increases faster than the mass, the fundamental floor resonance frequency tends to increase. A shift in the resonance frequency may be beneficial, detrimental, or have no effect depending upon the frequency of the dominant sources of vibration.

The second floor imaging spaces are designed as a waffle slab with a rib thickness of 12 in., initial depth of 38 in., slab thickness (before adding the topping) of 6 in., and a rib spacing of 10 ft. The topping is added after the initial structure is poured, and was likely treated by the structural engineers as added weight with no load-carrying benefit. From a vibration perspective, however, the additional concrete increases both the mass and the stiffness of the floor and both effects must be taken into account.

The effects of additional topping on the floor mass and stiffness are shown in Figure 2-1. The mass ratio is computed as the ratio of the cross-sectional area (*i.e.*, the mass) after adding topping to the cross-sectional area before adding the topping. Similarly, the stiffness ratio is based on the ratio of moments of inertia. An inset picture of the joist cross section in question is provided in the plot for reference. There is essentially no difference between the two curves—the mass and stiffness increase at roughly the same rate as topping thickness is increased from 0 in. to 12 in. Hence, for all intents and purposes, the floor system resonance characteristics are not affected by adding topping for the range of topping thickness used in the building. A 12-in-thick topping increases the waffle slab floor mass and stiffness by a factor of about 2.2.

The dynamic response of the floor benefits from the added mass and stiffness even though the resonance frequency does not change. A single-degree-of-freedom model of a floor system is used to illustrate the floor system response before adding the topping and the equipment, after adding the topping, and after adding the equipment. The acceleration response of each floor configuration is plotted in the left-hand side of Figure 2-2. The baseline structure (no topping or equipment) exhibits the highest response across the frequency spectrum and peaks at its resonance frequency (15.5 Hz). The addition of 12-in-thick topping does not alter the resonance frequency; however, the acceleration response is lower than the floor system before adding the topping. The equipment weight includes a typical MRI weight of 16 kips and an additional 4 kips of room and floor finishings. The additional equipment mass does not affect the floor stiffness and the lower resonance frequency is evident in the acceleration response plot.

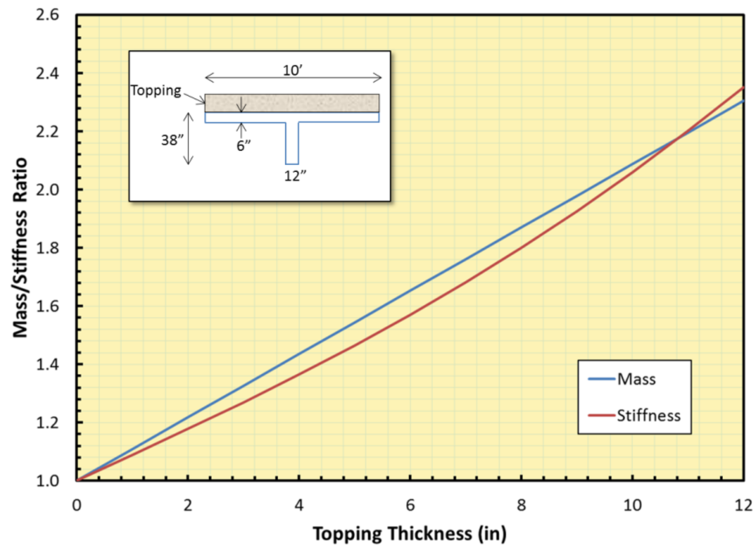



**Figure 2-1 Mass and Stiffness Ratio for Typical Joist with Varying Topping Thickness.**

The ratio of the acceleration response curves is shown in the right-hand side of Figure 2-2. The "Add Topping+Equip" curve on the right-hand side is the ratio of two acceleration response curves from the left-hand side of the figure (*i.e.*, Topping+Equip divided by No Topping/Equip). The "Add Equip" curve on the right-hand side is the ratio of the "Topping+Equip" and "Topping" curves on the left-hand side. Acceleration data acquired in a room without the topping (or equipment) should be scaled by the "Add Topping+Equip" curve, which reduces the vibration level across the spectrum because the magnitude of the curve is less than 1.0 for all frequencies. Data acquired in a room where the topping slab has been poured (or no topping slab will be poured) should be scaled by the "Add Equip" curve, which will increase the vibration by a factor of 2, but only near the floor resonance frequency.

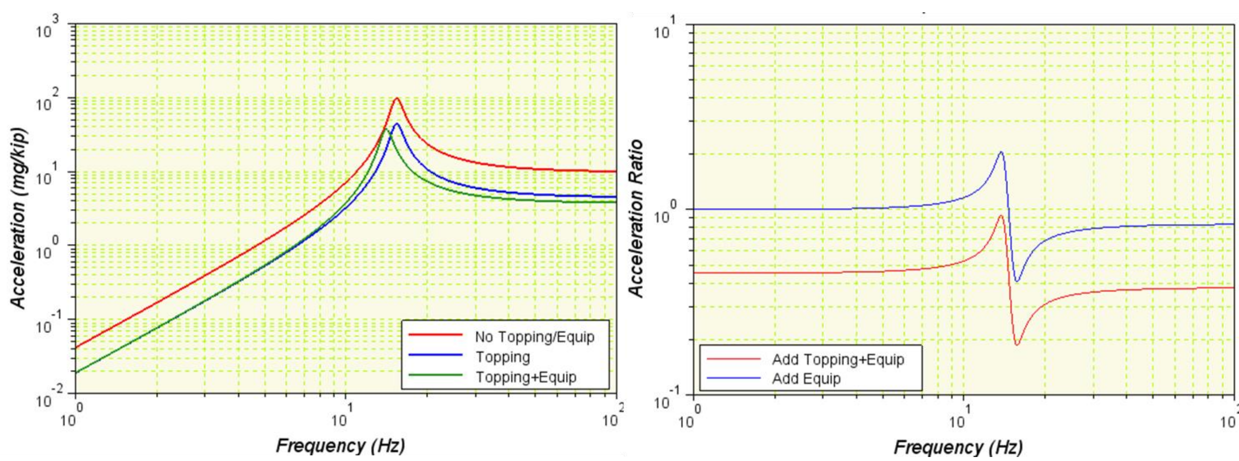



**Figure 2-2 Floor System Response (Left) and Ratio (Right) With and Without Topping and Equipment.**

## 2.2 WIND-INDUCED VIBRATION OF THE 17-STORY ACUTE TOWER

Wind-induced vibration of the building is a potential issue for the Somatom Definition AS64 CT imager located on the 16th floor. The General Notes, Ref. [9], state that a vibration isolation system is required for this imager at this location in the building. A structural dynamics model of a single bay (frame) of the Acute Tower is developed to determine the amplitude of the wind-induced motion of the structure. The lateral system in the tower is a combination of reinforced concrete moment frames and shear walls. There are two box-shaped elevator core wall systems and two independent shear walls in the tower. The stiffness of the shear walls is apportioned to the single frame of interest here in proportion to its contribution to that frame. The column and beam structural properties are determined from the construction documents. The vibration modes of the frame are obtained using SDAP, Ref. [13], and the first two lateral modes are plotted in Figure 2-3.

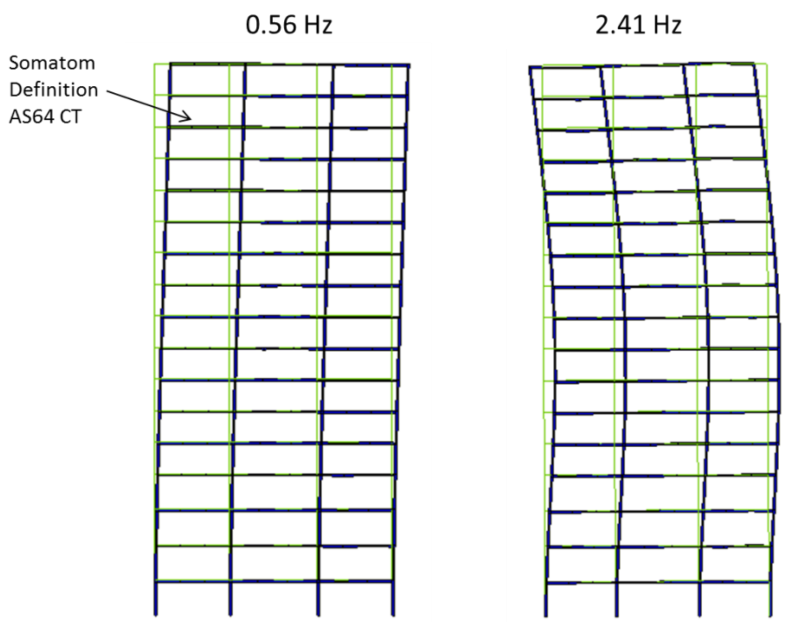



**Figure 2-3 First Two Sway Modes of the Acute Tower.**

The wind pressures used in the design of the Acute Tower are summarized in the Contract Documents, Ref. [14], and were obtained from Ref. [15]. These wind loads are intended for the structural design of the main wind force resisting system and therefore represent extreme conditions that correspond to a 90-mph, 3-sec-duration gust with a 7% probability of exceedance in a 50-year period. There is only a 0.14% probability that this gust wind speed will be exceeded in any given year.

A transient dynamics analysis is performed to determine the lateral acceleration at the location of the CT imager. The Code-specified wind loads are smoothly ramped from zero to the specified magnitude over 0.5 sec and then ramped back down to zero after 3 seconds at the full level. A structural damping level of 5% of critical is assumed. The lateral acceleration time history is plotted in Figure 2-4. The sway motion is dominated by the first mode of the bay at 0.56 Hz and reaches a maximum peak-to-peak acceleration of 75 mg.

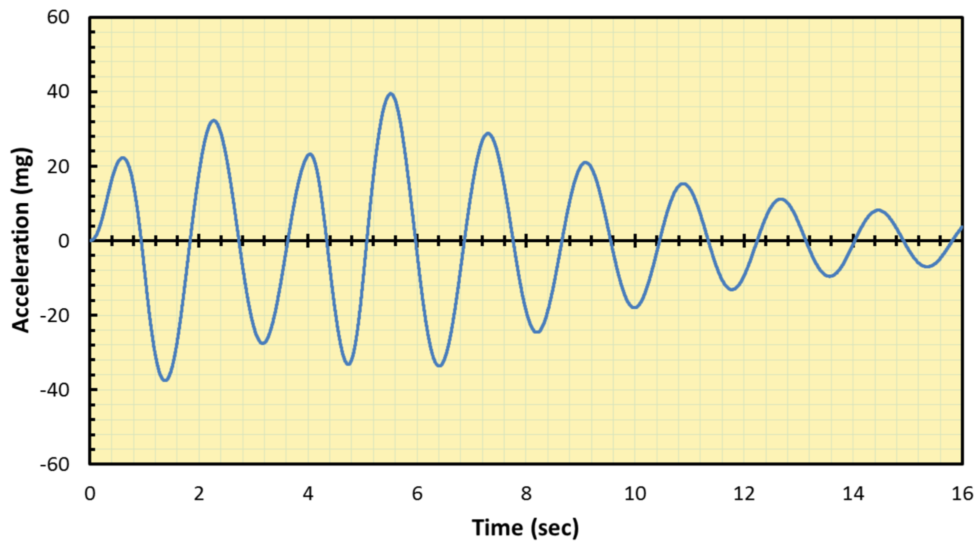



**Figure 2-4 Transient Dynamic Gust Response of the Acute Tower at the 16$^{th}$ Floor.**

# Section 3

## FLOOR VIBRATION MEASUREMENT AND ASSESSMENT

The vibration survey was conducted on January 7 and January 10, 2014. Data were acquired from 7:30 AM to 2:00 PM on January 7 and from 11:00 AM to 4:30 PM on January 10. Some construction worker foot traffic was present in the adjacent hallways and a variety of construction-induced noise and vibration was present throughout the measurement periods. The extraneous noise and vibration frequently exceeded that expected from normal hospital activity, but was not excessive. On-site construction managers were very accommodating in helping to reduce construction noise when asked.

### 3.1 DATA ACQUISITION EQUIPMENT AND MEASUREMENT PROCEDURE

Acceleration data are acquired using a portable data acquisition (DAQ) system consisting of a Windows-based laptop, a USB-powered four-channel 24-bit data acquisition module (Data Translation DT9837A), and the four single-axis accelerometers identified in Table 3-1. All three accelerometer models and the 24-bit DAQ are capable of measuring acceleration levels well below those required by the most sensitive equipment specifications. Channel 1 (PCB 393B31) has the lowest noise floor and is 10 times more sensitive than the other two accelerometer models.

**Table 3-1 Accelerometers and Channel Assignments**

| Channel | Accelerometer | S/N | Sensitivity |
|---|---|---|---|
| 1 | PCB 393B31 | 34729 | 9.88 V/*g* |
| 2 | PCB 333B52 | 46983 | 1.040 V/*g* |
| 3 | PCB 393B04 | 32502 | 1.003 V/*g* |
| 4 | PCB 393B04 | 32503 | 1.009 V/*g* |

The DAQ system is placed on a wheeled cart as shown in the left-hand side of Figure 3-1 to facilitate its relocation to the various rooms. Three of the accelerometers are stud-mounted on three mutually orthogonal faces of a 3-in. steel cube (mounting block) as shown in right-hand side of Figure 3-1. The PCB 333B52 (Channel 2) is a back-up accelerometer that is mounted with bees wax adjacent to Channel 1. The mounting block is placed at the anticipated location of the imager's isocenter. The measurement axes are aligned with the room's walls (plan North and East) and in the vertical direction. The most sensitive accelerometer, Channel 1, is normally oriented to measure vibration in the up direction. When data are acquired in the most sensitive MRI rooms, three separate measurements are made with Channel 1 orientated in the north, east, and up directions in succession.

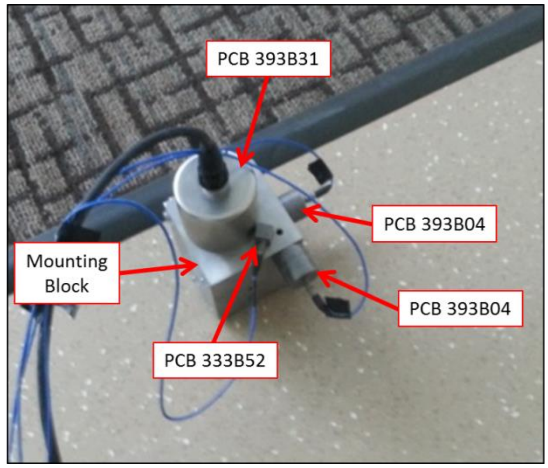




**Figure 3-1 Portable Data Acquisition System.**

Data are acquired with a sampling frequency of 1000 Hz, which implies a low-pass anti-aliasing filter at 500 Hz. The 500-Hz measurement bandwidth merely needs to be larger than the bandwidth required by the vibration specifications which only extend out to 100 Hz. Continuous data acquisition periods of 5, 10, and 15 minutes are used, depending upon the sensitivity of the equipment that will be placed in that space and the level of nearby construction activity.

## 3.2 DATA OVERVIEW

The data acquisition process produces ASCII text files containing one column for time and four columns of acceleration data corresponding to each accelerometer channel. The raw accelerometer time series data are analyzed using signal processing routines developed using Scilab (Ref. [12]). The raw data are in the time domain, but the manufacturer's vibration specifications are routinely presented in the frequency domain. The conversion from the time domain to the frequency domain is performed with the Fast Fourier Transform algorithm implemented in Ref. [12]. The time-frequency spectrogram is then computed and used to identify transient events and periods when the data have a consistent character with respect to frequency content and amplitude (*i.e.*, are stationary). The power spectrum provides the vibration amplitude in power spectral density (PSD), measured in $g^2$/Hz, across the frequency domain during the stationary periods and is the starting point for computing the narrowband and proportional-band RMS acceleration spectra needed to compare with the room environment specifications.

### 3.2.1 TIME-FREQUENCY ANALYSIS

The time-frequency spectrogram provides a very useful overview of the data in both the time domain and the frequency domain. Shorter-duration 8-sec-long time segments are successively converted into the frequency domain, color-coded based on amplitude, and plotted as horizontal lines corresponding to the time when that 8-sec data segment is recorded. The time-frequency spectrogram is used to identify changes in the frequency content during the measurement period that might be caused by transient events such as passing vehicular traffic, an object hitting the floor, or turning on/off a mechanical system.

Two representative time-frequency spectrograms computed from data obtained in E2122 and E4193 are provided in Figure 3-2. Thin vertical lines represent rotating machinery such as the lines highlighted in the figure at 30 Hz. A 30-Hz frequency corresponds to a motor operating at 1800 RPM. Broad vertical features may represent amplified vibration near a floor resonance frequency or the initiation of some vibration source like the flow noise identified in the figure.

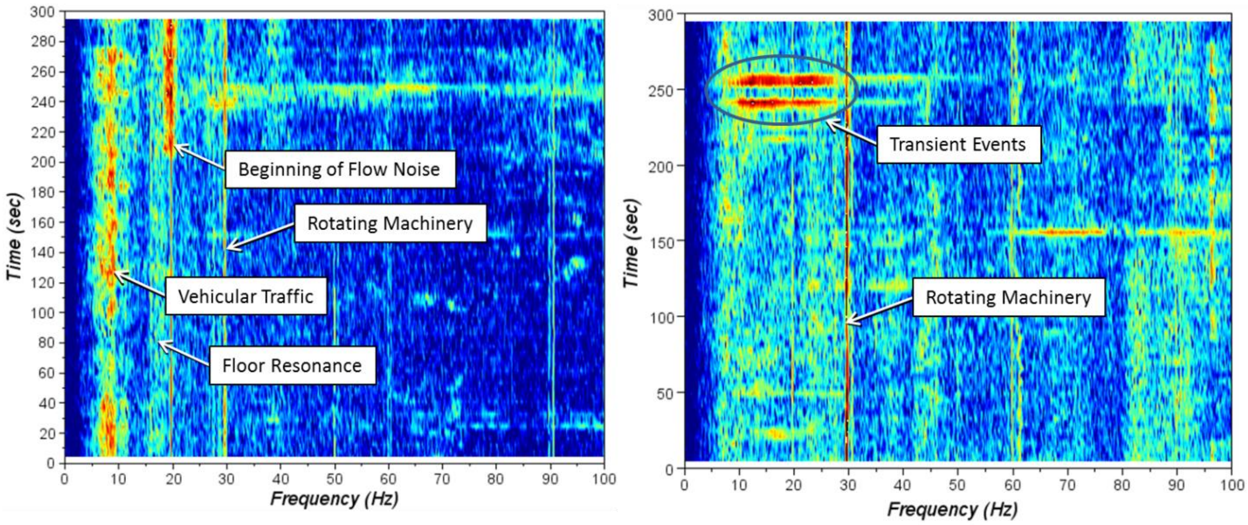



**Figure 3-2 Representative Time-Frequency Spectrograms for E2122 (Left) and E4193 (Right).**

Transient events show up as horizontal features. Two transient events are identified in the right-hand side of Figure 3-2. In this case, these transient events are caused by a construction worker pushing a wheeled cart loaded with various tools and metal parts in the corridor outside the room where the measurements were being acquired. Clearly identifiable construction noise is not representative of normal hospital operation and can be ignored for the purpose of evaluating the vibration level in these rooms.

### 3.2.2 POWER SPECTRA

Power spectra show how vibration energy is distributed across the frequency domain. The power spectrum computed from the (mostly) stationary portion of the data measured in E4193 is plotted in Figure 3-3. The stationary portion of the data occur before the two transient events shown in the right-hand side plot in Figure 3-2. The power spectrum is an average of the 8-sec-long data segments (8192 samples/segment). Each segment overlaps the previous segment by 50% (4096 samples). The Hanning data window is applied to each data segment, as required by the vibration specifications, to reduce the effects of leakage. The sampling frequency (1000 Hz) and data segment length (8192 samples) determine the frequency resolution, $\Delta f$ = 0.122 Hz, of the power spectrum.

The large-amplitude and very narrow peak at 30 Hz is caused by structure-borne vibration transmitted to the space by the mechanical units located across the corridor in E4100. The other lower-amplitude, narrow peaks visible in the power spectrum are also likely caused by that or other mechanical units in the complex; however, the spike at 60 Hz may be electrical noise produced by the electrical outlet the DAQ is plugged into.

The power spectrum is the fundamental information required to compute the RMS vibration for specifications based on the narrowband or proportional band spectra discussed in Section 1.2. The boundaries of the narrowband and 1/3-octave bandwidths centered at 10 Hz are also illustrated in the figure. The RMS level for each band is merely the square root of the area under power spectrum bounded by the extents of the respective bandwidth.

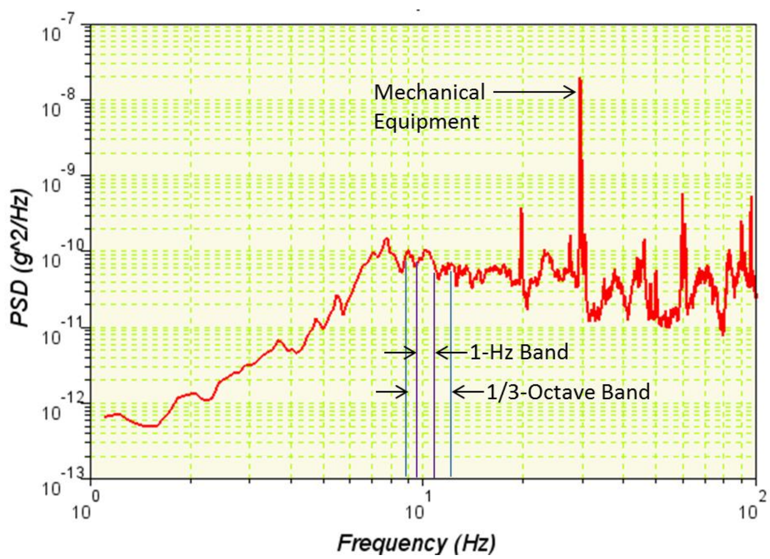



**Figure 3-3 Power Spectrum for E4193.**

## 3.3 FLOOR VIBRATION ASSESSMENT

The vibration assessment is divided into four categories based on the vibration sensitivity and commonality of the governing vibration criteria. Four of the 18 spaces house MRIs, which are the most sensitive spaces identified in this study. Somatom CT imagers also have documented criteria and are assigned to six of the rooms. Miscellaneous imagers with no formal documented criteria are assigned to seven rooms. The ISO criterion for operating rooms is used to assess the vibration performance for these rooms. The corridor on the 4$^{th}$ floor is also assessed for pedestrian-induced vibration using the operating room criterion. An overall vibration assessment summary is provided in Table 6-1 in Appendix A and room-by-room summary sheets are provided on Pages 6-2 through 6-7.

### 3.3.1 MAGNETIC RESONANCE IMAGING SPACES

The four rooms identified to receive MRIs are E2122, E2124, E2129, and E4193. Construction noise in excess of that produced during normal hospital operations was present while acquiring measurements in some of the rooms; however, all four of the MRI rooms satisfy the vibration specifications. The summary vibration assessment sheets for Rooms E2122, E2124, and E2129 are provided in Appendix A on Pages 6-5 and 6-6. The room assessment summary sheet for E4193 is provided on Page 6-7.

The up-down vibration environment measured in E2129 is represented by the time-frequency spectrogram and the narrowband spectrum provided in the left- and right-hand sides of Figure 3-4, respectively. A high-speed rotary tool (*e.g.*, a drill) was being used elsewhere on the floor and is responsible for the high-amplitude 46-Hz vibration clearly identifiable in the time-frequency spectrogram and the peak at the same frequency in the narrowband spectrum. Even with this non-representative vibration, the averaged narrowband response spectrum (thick red line) falls well below requirement. The narrowband response spectra obtained from each of the 8-sec-long data segments are also plotted in the right-hand-side figure for reference to illustrate the variability of the vibration environment.

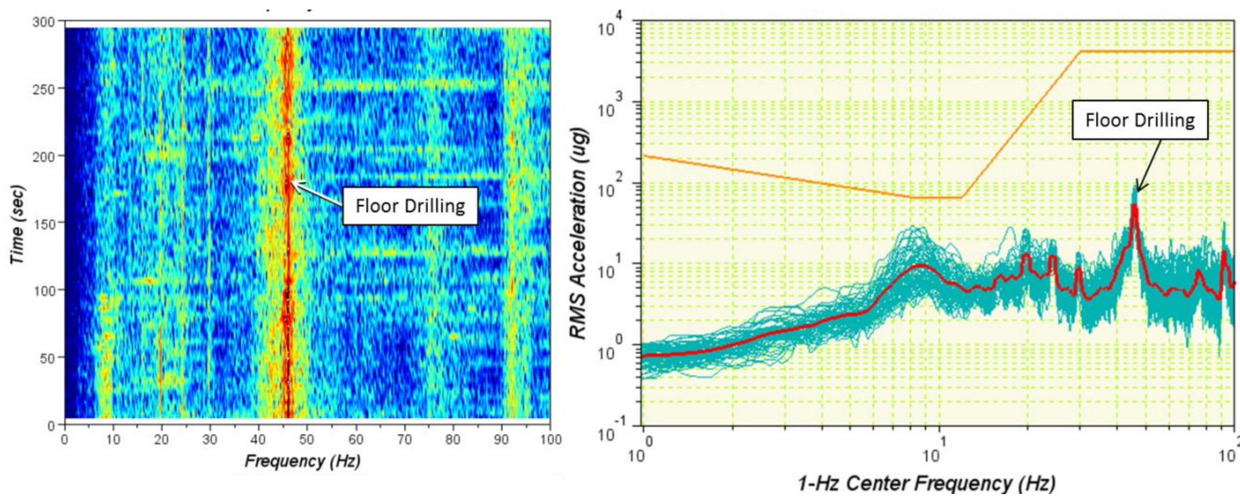



**Figure 3-4 Time-Frequency Spectrogram (Left) and Narrowband Spectrum (Right), E2129.**

The 12-in. topping slab is present in Rooms E2122, E2124, and E2129; hence, a slight increase (×2) in the vibration environment near the floor's dominant resonance frequency is expected when the mass of the MRI is added to the floor based on the analysis presented in Section 2.1. The floor response to one of the heel-drop tests conducted in E2129 is shown in Figure 3-5, which indicates that the dominant floor resonance frequency is near 20 Hz. The narrowband response magnitude is about 13 $\mu g_{RMS}$ at 20 Hz and when doubled to account for the MRI weight is still far below the allowed level of 600 $\mu g_{RMS}$. Hence, the installation of the MRI will have very little effect on the vibration performance of this room.

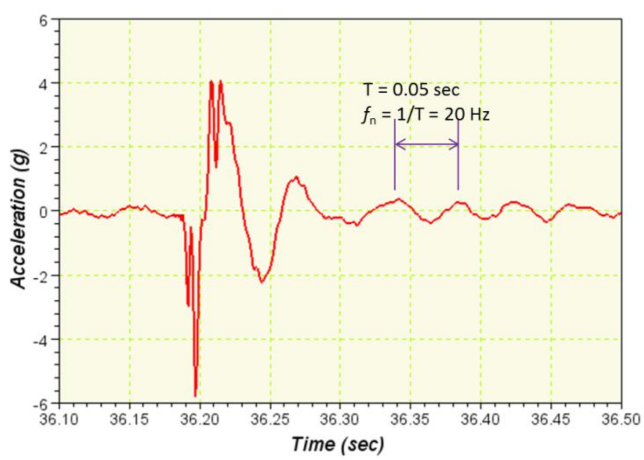



**Figure 3-5 E2129 Floor System Response to Heel Drop Test.**

The vibration environment recorded in E2122 exhibits different vibration characteristics from that measured in E2129. The time-frequency spectrogram and narrowband spectrum for this space are provided in the left- and right-hand sides of Figure 3-6, respectively. First, the rotary tool is not operating so the high-amplitude, 46-Hz vibration is not present. However, floor vibration near 8 Hz—the frequency where the MRIs are most sensitive—is much more pronounced than that measured in E2129 about 1 hour earlier. The increased vibration between 6 and 10 Hz may be caused by one or more construction vehicles operating on the south side of the building. Many vehicles have an axle-hop mode[1] in this frequency range that is responsible for generating ground-borne vibration. This low-rise area of the building may also have a column vibration mode near 8 Hz that amplifies any ground-borne vibration in this frequency range. The column mode, if present, is a characteristic of the building's construction that will be present when the hospital is operational; however, any vibration created by construction equipment will not be present once all construction activities on the site are complete.

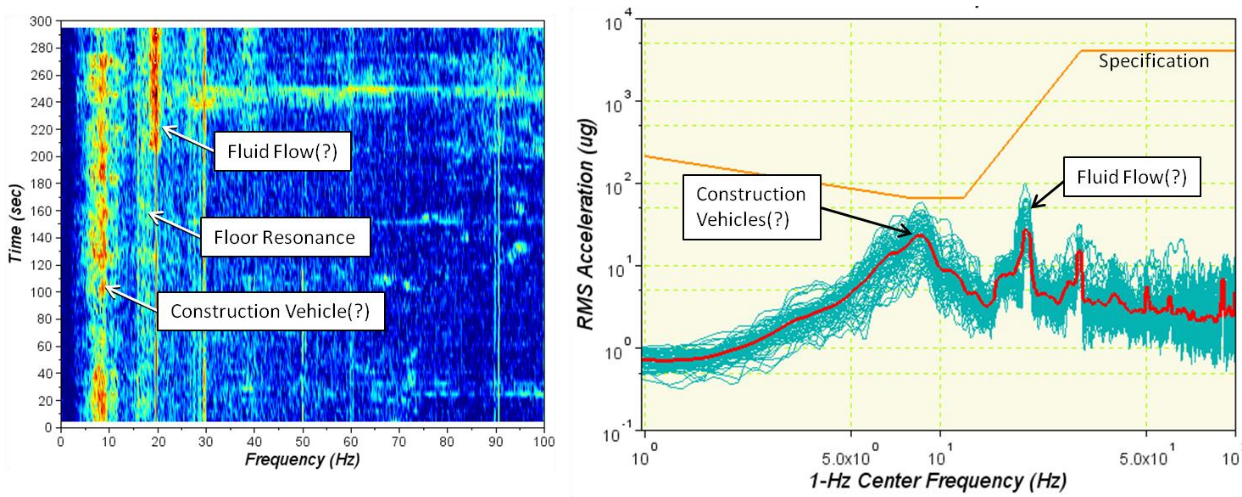



**Figure 3-6 Time-Frequency Spectrogram (Left) and Narrowband Spectrum (Right), E2122.**

A significant vibration source at 20 Hz appears at 200 sec, which may be amplified by the floor system's resonant mode(s). The source of this vibration is not known but may be caused by fluid flow through pipes and may therefore be present when the hospital becomes operational. The vibration requirement at 20 Hz is much less demanding than it is near 8 Hz so this vibration source does not raise the concerns that the 8-Hz vibration does.

The time-frequency spectrogram and narrowband spectrum obtained from E4193 are provided in the left- and right-hand sides of Figure 3-7, respectively. The topping slab is not present in this room and the analysis presented in Section 2.1 indicates that the effect of the topping slab and MRI weight will only reduce the vibration environment relative to the measurements obtained during the site survey. The time-frequency spectrogram shows evidence of two high-amplitude transient events (rolling cart) and a fairly strong contribution at 30 Hz from the mechanical units located across the corridor in E4100 and/or on the roof above.

The averaged narrowband spectrum is plotted in the right-hand side of Figure 3-7 as the thick red line and it satisfies the MRI specification by a minimum factor of 15. Once again, the individual narrowband spectra from each of the 8-sec-long segments are also plotted for reference. The contribution of the rolling cart transient is evident as the three lines (segment spectra) that rise well above the average response between 10 and 30 Hz. Two of these 8-sec-duration spectra actually violate (*i.e.*, cross) the specification line. This "violation" is not of concern because: (1) the specification is intended to be assessed with an averaged spectrum rather than a short-duration spectrum, (2) the specification level is increased by a factor of 4 (per Ref. [1] and Ref. [2]) for legitimate transient events, and (3) these transient events are not "legitimate" because they result from construction activity rather than normal hospital operations.

[1] Vehicles have two dominant modes of vibration; a low-frequency suspension mode (about 1 Hz) and a higher-frequency axle-hop mode that results from the flexibility of the tires and frame and the mass of the vehicle.

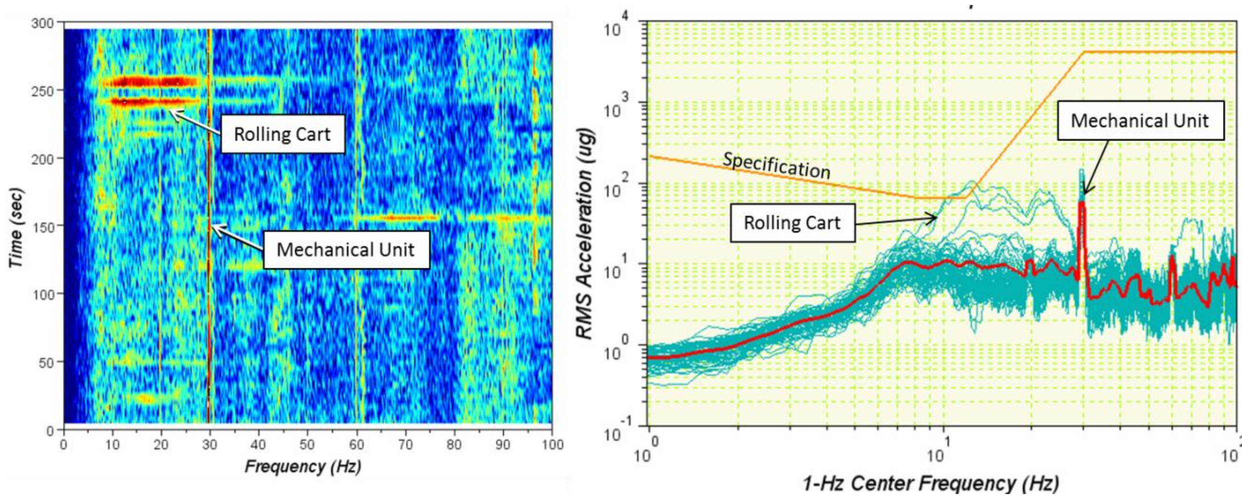



**Figure 3-7 Time-Frequency Spectrogram (Left) and Narrowband Spectrum (Right), E4193.**

### 3.3.2 SOMATOM COMPUTED TOMOGRAPHY IMAGER SPACES

Two different models of Somatom Definition CT imagers will be placed in six of the 18 rooms: A1186, A1188, A2191, E2101, E2102, and D16119. These imagers are not particularly vibration sensitive as noted in Section 1.2; however, Siemens does provide vibration specifications in the form of narrowband spectra for the AS series and Flash imagers. In spite of the fact that construction activity was quite high in some cases, all six of the identified rooms satisfy the vibration criteria with significant margin.

A construction worker was surfacing the floor with a high-speed rotary tool in the corridor very near Rooms A1186 and A1188 when those vibration data were acquired. A dominant 60-Hz vibration produced by the tool is clearly visible in the corresponding time-frequency spectrograms and in the narrowband spectra (see Page 6-2 in Appendix A); however, both rooms can tolerate 100 times this vibration without violating the imager specifications. At the other extreme, the vibration measurements in A2191 are obtained during the lunch hour when construction activity is at a minimum, resulting in ambient vibration levels 1000 times lower than the specification.

One of each type of imager, the Flash CT and the AS64 CT, will be placed in E2101 and E2102, respectively. The two rooms are adjacent to one another and the final topping slab was not present at the time the vibration data were acquired. The narrowband spectra obtained in both rooms are plotted in Figure 3-8. The measured vibration levels fall well below the specification limits. As is normally the case, the up-down vibration dominates over the north/south and east/west vibration. The up/down vibration measured in E2102 is generally higher than that measured in E2101 because fluid flow noise around 20 Hz was present during most of the E2102 measurement period. Nevertheless, the flow noise, which is likely to occur during normal hospital operations, does not represent any concern from a vibration perspective and the addition of the topping slab is expected to further reduce the vibration levels in these two rooms.

A Somatom Definition AS64 CT imager will be located on the 16$^{th}$ floor of the Acute Tower and is therefore much more susceptible to wind-induced vibration of the tower than are the imagers located on the lower floors. The time-frequency spectrogram and corresponding narrowband spectra are shown in the left- and right-hand sides of Figure 3-9, respectively. The measured vibration does not account for the wind-induced sway motion of the tower because there was very little wind at the time the data were acquired; however, the structure-borne and ground-borne vibration sources are present. Two significant construction transients occurred between 2 and 3 minutes into the data recording period when construction workers set up and then repositioned a ladder in the corridor outside of D16119. These relatively high-amplitude construction transients are identified in the time-frequency spectrogram and are most intense between 50 and 70 Hz. Even with this high-amplitude and non-representative vibration source, the measured vibration environment easily satisfies the requirement.

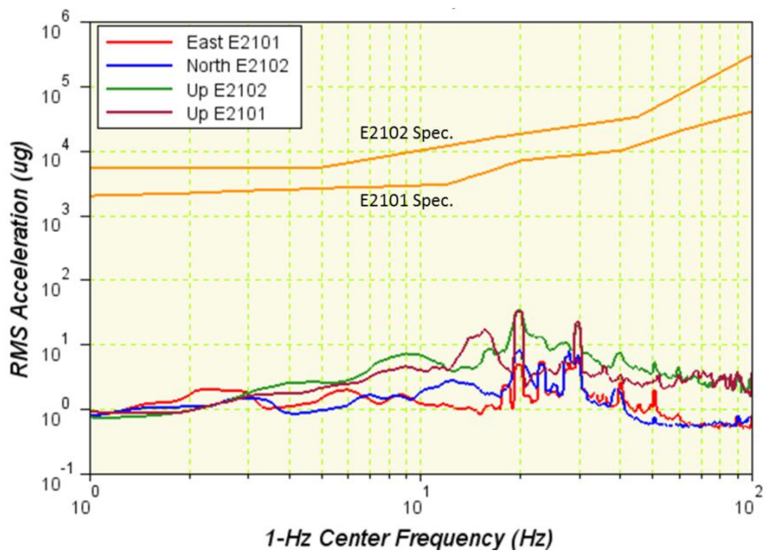



**Figure 3-8 Narrowband Spectra from E2101 and E2102.**

No topping slab will be placed in D16119 so the addition of the imager mass (about 5,000 lbf) will tend to increase the vibration level near the floor's resonance frequency. Persistent floor vibration near its current resonance frequency is clearly visible in the time-frequency spectrogram (left side of Figure 3-9) as the fairly broad vertical band near 15 Hz. The mass of the CT imager is about one-third that of an MRI, so its effect on the resonance frequency will be fairly minimal (about 0.5 Hz lower), and its effect on the floor's vibration response reduces from ×2 to about ×1.5. The measured vibration near 15 Hz is about 70 $\mu g_{RMS}$, which may increase to about 105 $\mu g_{RMS}$ after the imager is installed. Even after taking this increased level of vibration into account, the vibration environment in the room is expected to be 100 times lower than allowed by the AS64 specification. Ground-borne and structure-borne vibration are not expected to pose any problems with imager performance.

Wind-induced vibration must be addressed via the analysis presented in Section 2.2. Potentially troublesome wind-induced motion is short-lived (less than 10 sec) and is therefore a form of vibration transient. The AS64 specification, Ref. [4], states that vibration transients must be less than 0.5 m/sec$^2$ (51 mg peak-to-peak) while performing a scan. The predicted peak-to-peak wind-induced lateral acceleration at the 16$^{th}$ floor is 75 mg, which does exceed the imager's specification. However, it is worthwhile to consider the probability that a wind gust significant enough to impair imager performance will occur while the imager is operating.

The gust response analysis is based upon a Building-Code-specified gust wind speed of 90 mph, which has a 0.14% probability of being exceeded in any given year. The minimum gust wind speed that can impair imager performance is about 75 mph based on the ratio of the calculated acceleration obtained for 90 mph and the permitted acceleration of 51 mg. The return period, *T*, for a 75-mph gust is

$$T = \frac{1}{12} e^{10(75/90-0.36)} = 9.2\,\text{years} \tag{2}$$

which implies that imager performance may be impaired once every 9 years, assuming the imager operates continuously during those 9 years. If, on the other hand, the CT imager is used 4 hours/day on average, the probability of impaired performance drops to once every 50 years. In other words, it is highly unlikely that wind-induced sway motion of the Acute Tower will affect the imager's performance in the lifetime of the hospital, let alone the lifetime of the imager.

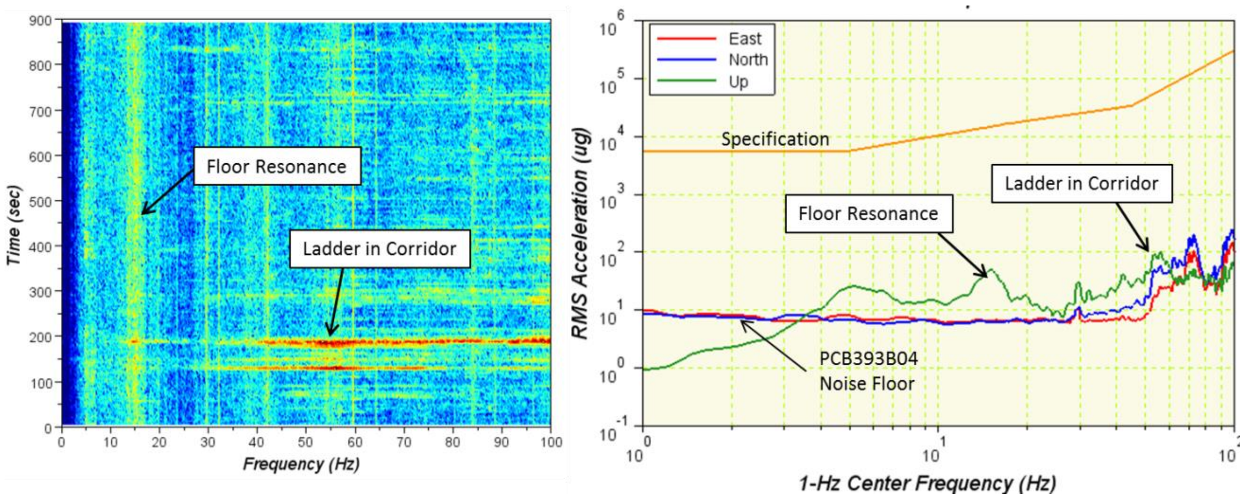



**Figure 3-9 Time-Frequency Spectrogram (Left) and Narrowband Spectrum (Right), D16119.**

### 3.3.3 MISCELLANEOUS IMAGER SPACES

The remaining imagers scheduled for Rooms A2103, A2139, A2142, A2144, A2147, A2149, and A2152 do not have quantitative vibration specifications. These specifications merely require a typical "clinical environment," which is interpreted as the ISO operating room requirement (Figure 1-3) for the purposes of this investigation. The ISO requirement is probably more demanding than these imagers require, considering that the operating room requirement is more demanding than the Somatom Definition AS and Flash vibration requirements. Minimal construction activity was present during data acquisition in these spaces and all seven of these rooms satisfy the adopted vibration criteria with significant margin to spare.

Rooms A2139 through A2152 are adjacent to one another and the partitions that will eventually separate and define these rooms are not installed. The topping slab is not present; hence, the addition of the equipment will not adversely affect the vibration environment. Given the relative vibration insensitivity of the imagers identified for these six rooms and the identical construction of the floor system in this contiguous space, vibration data are acquired in A2139 and A2149 to represent these six rooms. The 1/3-octave band spectra are shown in Figure 3-10. As expected, the up-down vibration spectra obtained in A2139 and A2149 (about 40 ft apart) are virtually identical. Furthermore, the measured vibration level is about 150 times less than allowed by the ISO specification for operating rooms. The absence of construction activity, including foot traffic in the surrounding corridors provides the most optimistic vibration assessment; however, routine hospital operations will not affect this assessment.

No east/west spectrum is plotted in Figure 3-10 because the wire connecting the accelerometer to the data acquisition module developed an intermittent short at some point during the measurement activity. The absence of data in the east/west direction is not of concern because the vibration level parallel to the floor is negligible and the adopted vibration specification far exceeds even the worst-case vibration in the up/down direction.

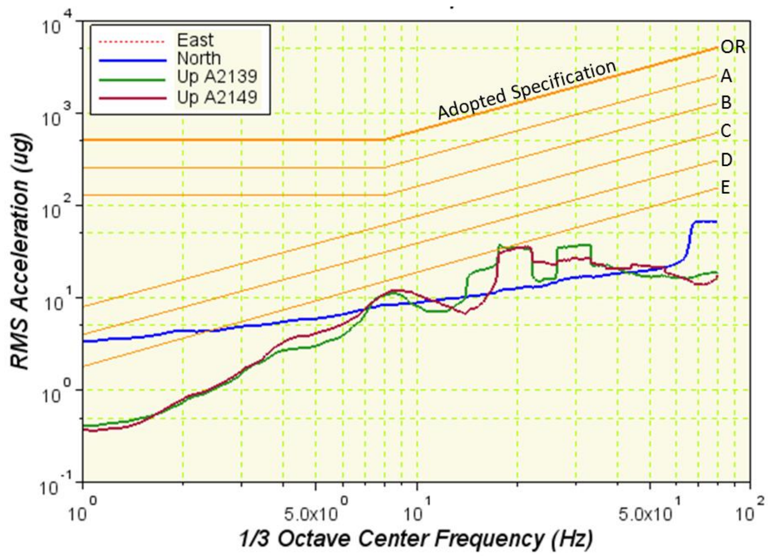



**Figure 3-10 Miscellaneous Equipment Evaluation: Rooms A2139 Through A2152.**

### 3.3.4 4TH FLOOR CORRIDOR ABOVE OPERATING ROOMS

Corridor C4C01 passes over one end of three operating rooms on the 3rd floor below and the effectiveness of any equipment supported from the ceiling of the operating rooms can be adversely affected by excessive walking-induced vibration on the floor above. The ISO operating room vibration requirement, expressed in terms of ceiling (4th floor) velocity, is used to assess the corridor structure. The General Notes, Ref. [9], state that the maximum-allowed velocity be assessed based on one person walking along the corridor at a pace of 100 steps/min.

A smartphone metronome application[2] set to 100 beats/min is used to establish the walking pace as data are simultaneously acquired on the floor. The floor (operating room ceiling) RMS velocity, computed in 1/3-octave bands is shown in Figure 3-11 for the ambient vibration (no walking) and the walking-induced vibration environments. The primary effect of the pedestrian traffic in the corridor is evident at the step rate of 1.7 Hz; however, the maximum floor velocity occurs around 8 Hz and is largely independent of pedestrian traffic in the corridor. The vibration near 8 Hz may be caused by ground-borne vehicular vibration and/or vertical “pogo” oscillation modes of the building’s columns. The floor system’s resonance frequencies fall in the 25-Hz range based on heel-drop test data obtained in the corridor. Nevertheless, the maximum floor velocity is about 500 μin/sec (mips), which is much lower than the 4000 μin/sec allowed by the ISO operating room vibration specification (and Ref. [9]). Walking-induced vibration will not be noticeable to hospital staff working in the operating rooms below the C4C01 corridor.

[2] Mobile Metronome for Android, Version 1.2.4F (2012)

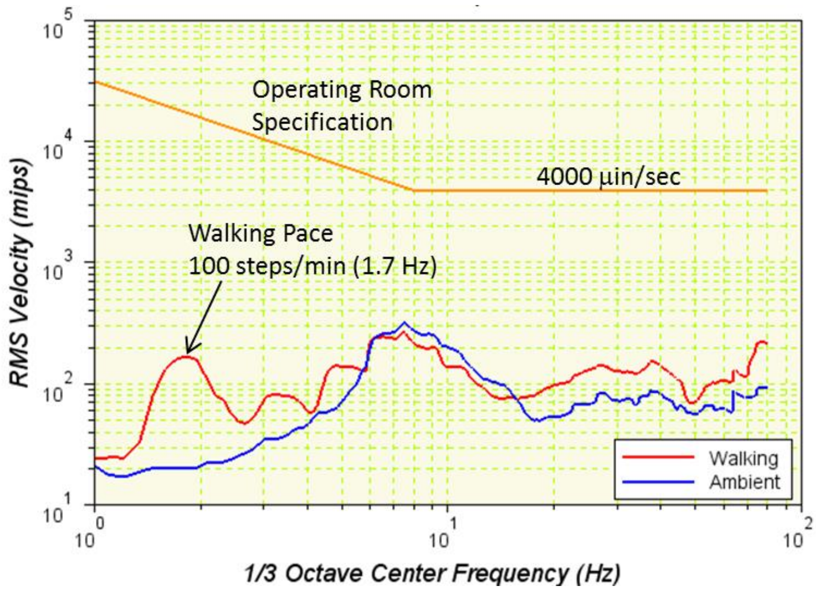



**Figure 3-11 Ambient and Walking-Induced Vibration in Corridor C4C01.**

# Section 4

## CONCLUSIONS AND RECOMMENDATIONS

The vibration survey of the critical imaging spaces in The New Parkland Hospital requested by PHHS was conducted concurrent with ongoing construction activity. In some cases, the use of high-speed rotating machinery (*e.g.*, drills and sanders) produced vibration far in excess of normal hospital operations. On-site BARA construction managers were very cooperative and accommodating when asked to temporarily suspend the construction activity responsible for excessive vibration. The measured vibration accounts for structure-borne vibration from operating mechanical systems and construction personnel and ground-borne vibration from nearby roadways, the construction site, and a DART light rail track. The measured vibration ranges between representative of or higher than normal hospital operations.

The addition of the 12-in-thick topping slab and/or the imaging equipment, which can weigh up to 20,000 lbf, will alter the vibration characteristics of the floor systems as measured during the site survey. Structural dynamics analyses show that the vibration performance of those rooms that will receive the topping slab and the equipment will improve relative to the measured performance. The vibration performance of those rooms that already have the topping slab or are not intended to have a topping will be slightly worse in a narrow frequency range centered on the floor's resonance frequency when the equipment is installed. The analyses indicate that the vibration will be increased by a factor of 1.5 to 2.0 times the measured vibration near the floor's resonance frequency, which tends to fall in the 15- to 25-Hz range depending upon the location within the building.

The imaging spaces evaluated as part of this investigation satisfy the documented or adopted vibration criteria with significant margin in most cases. The added weight of the equipment and room finishings may slightly degrade the vibration performance of some rooms in a narrow frequency range; however, the effect will not cause any of the rooms to violate their vibration requirements. The current vibration level in the MRI spaces is about 10 times lower than allowed by the MRI vibration specifications. The margin is less in E2122; however, the higher vibration levels measured in this space may be caused by on-site construction vehicle activity. PHHS should consider a follow-up vibration survey focused on Rooms E2122 and E4193 once construction activities have concluded, all major mechanical systems are installed and operating, and the imagers are installed.

The vibration levels measured in the CT and other imager spaces is about 100 times lower than that allowed by those vibration specifications. The addition of the much lighter-weight CT imagers will have very little effect on the vibration performance of these rooms. Walking-induced vibration of the 4$^{th}$-floor corridor over the 3$^{rd}$-floor operating rooms is only apparent near 2 Hz. This frequency, and its first two harmonics, are much lower than the floor structure resonance frequency of 25 Hz and therefore have very little effect. The ambient vibration levels in the 6- to 10-Hz range control but are about 8 times lower than the maximum-allowed limit. Ceiling-supported equipment in these operating rooms should not be affected by corridor floor structure vibration.

The General Notes, Ref. [9], state that the CT imager on the 16$^{th}$ floor must be mounted on a vibration isolation system to prevent lateral wind-induced sway motion of the tower from adversely affecting imager performance. Structural dynamics analyses do show that Building-Code-specified gust wind pressures will give rise to peak-to-peak tower accelerations that exceed the imager's transient vibration requirement. Building Code wind loads, however, are intended for the design of the main wind force resisting system of the building and therefore have a very low probability of occurrence. The analyses indicate that imager performance may be affected only once in the operational lifetime of the imager when gust wind speeds exceed 75 mph while the imager is in use. PHHS may want to consider the need for the vibration isolation system given the very low probability that wind-induced sway motion will affect the imager.

# Section 5

## REFERENCES


[1] Siemens Healthcare Equipment Submittal 16880A-1, Skyra 3.0T MRI, New Parkland Health & Hospital System, Project No. 1302005, Drawing No. S-101, August 16, 2013.

[2] Siemens Healthcare Equipment Submittal 28101A, Aera 1.5T MRI, New Parkland Health & Hospital System, Project No. 1302002, Drawing No. S-101, August 16, 2013.

[3] Siemens Healthcare Equipment Submittal 16508A, Somatom Definition Flash CT, New Parkland Health & Hospital System, Project No. 1301995, Drawing No. S-501, August 9, 2013.

[4] Siemens Healthcare Equipment Submittal 11570A, Somatom Definition AS64 CT, New Parkland Health & Hospital System, Project No. 1301998, Drawing No. S-501, August 12, 2013.

[5] Siemens Healthcare Equipment Submittal 22327E, Symbia S, New Parkland Hospital, Project No. 1300658, Drawing No. S-101, July 9, 2013.

[6] Siemens Healthcare Equipment Submittal 24713E, Symbia T, New Parkland Hospital, Project No. 1300655, Drawing No. R-501, March 5, 2013.

[7] Siemens Healthcare Equipment Submittal 27314E, Symbia T, New Parkland Hospital, Project No. 1300657, Drawing No. S-501, August 27, 2013.

[8] Siemens Healthcare Equipment Submittal 20636A, Biograph mCT.S/X, New Parkland Hospital, Project No. 13000654, Drawing No. S-101, August 20, 2013.

[9] Parkland Health & Hospital System, Contract Documents, "General Notes," Drawing No. S-001, February 1, 2013.

[10] International Standards Organization, "Mechanical Vibration and Shock – Evaluation of Human Exposure to Whole Body Vibration – Part 1, General Requirements," ISO 2631-1, 1974.

[11] Amick, H., Gendreau, M., Busch, T., and Gordon C., "Evolving Criteria for Research Facilities: I – Vibration," *Proceedings of SPIE Conference 5933: Buildings for Nanoscale Research and Beyond*, 2005.

[12] Consortium Scilab - Digiteo (2011), *Scilab: Free and Open Source Software for Numerical Computation*, Version 5.3.2 [Software].

[13] Lamb, James L., *Structural Dynamics Analysis Program (SDAP)*, Version 2013-02-26, February 2013 [Software].

[14] Parkland Health & Hospital System, Contract Documents, “General Notes, Abbreviations, and Symbols,” Drawing No. S-000, February 1, 2013.

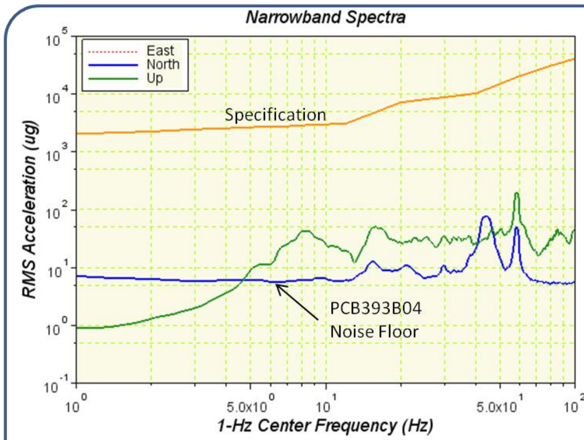
[15] American Society of Civil Engineers, Minimum Design Loads for Buildings and Other Structures, ASCE-SEI 7-15, 2005.

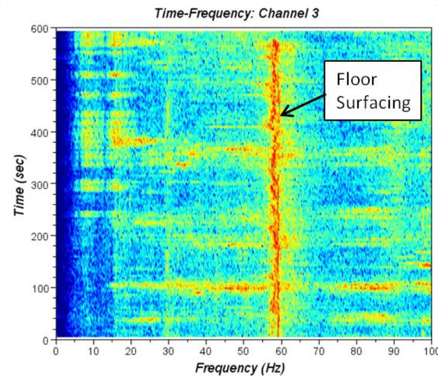
# Section 6

## APPENDIX A: ROOM VIBRATION DATA SHEETS

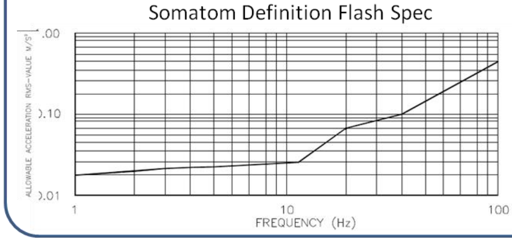
**Table 6-1 Room Vibration Assessment Summary.**

| Room | Pass/Fail | Comment | Page |
|---|---|---|---|
| A1186 | Pass | Significant construction activity (floor surfacing). | 6-2 (top) |
| A1188 | Pass | Significant construction activity (floor surfacing). | 6-2 (bot) |
| A2103 | Pass | Very little activity. | 6-3 (top) |
| A2139 | Pass | Very little activity. Topping slab not present. | 6-3 (bot) |
| A2141 | Pass | Very little activity. Topping slab not present. | 6-3 (bot) |
| A2142 | Pass | Very little activity. Topping slab not present. | 6-3 (bot) |
| A2148 | Pass | Very little activity. Topping slab not present. | 6-3 (bot) |
| A2149 | Pass | Very little activity. Topping slab not present. | 6-3 (bot) |
| A2152 | Pass | Very little activity. Topping slab not present. | 6-3 (bot) |
| A2191 | Pass | Very little activity. Topping slab not present. | 6-4 (top) |
| E2101 | Pass | Very little activity. Topping slab not present. | 6-4 (bot) |
| E2102 | Pass | Some flow noise. Topping slab not present. | 6-5 (top) |
| E2122 | Pass | Outside vehicle(?) and flow noise. Topping present. | 6-5 (bot) |
| E2124 | Pass | No significant activity. Topping present. | 6-6 (top) |
| E2129 | Pass | Floor drilling(?) ~50 ft away. Topping present. | 6-7 (bot) |
| E4193 | Pass | Brief hallway activity. Topping slab not present. | 6-8 (top) |
| C4C01 | Pass | No additional activity. Walking at 100 steps/min. | 6-8 (bot) |
| D16119 | Pass | Brief hallway activity (ladder setup and relocation). | 6-9 (top) |

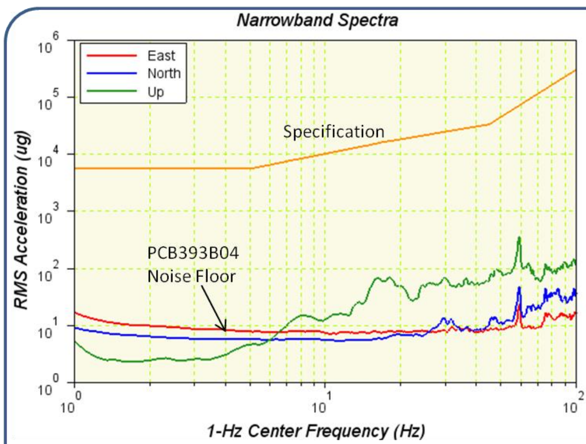


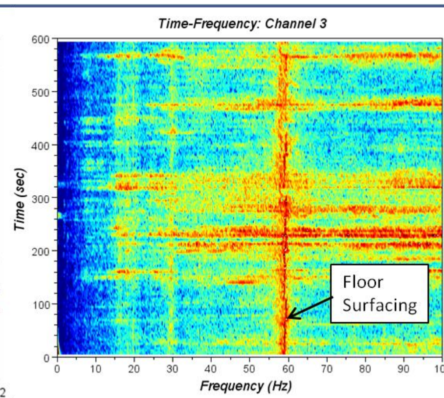




Somatom Definition Flash Spec

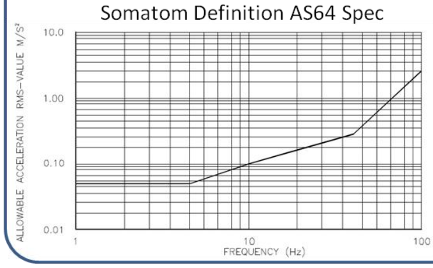



Room: A1186
Equip: 16508A
Findings:
Floor sanding during data acquisition. Vibration easily satisfies spec.

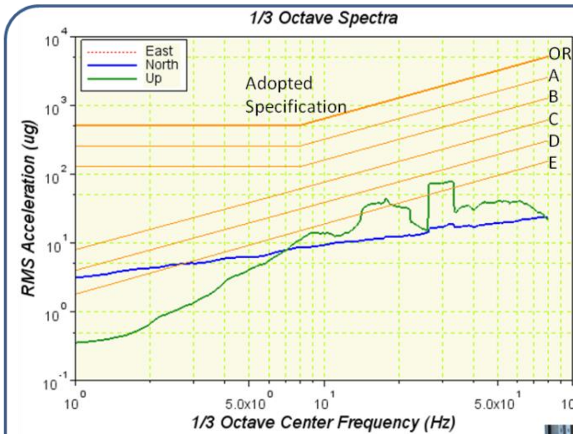


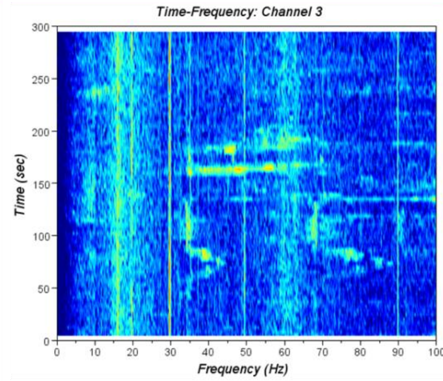




Somatom Definition AS64 Spec

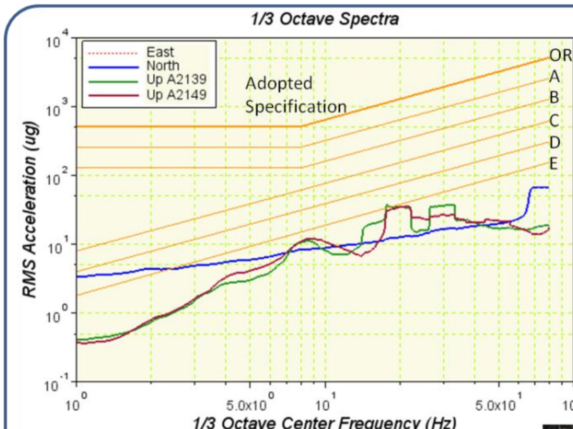


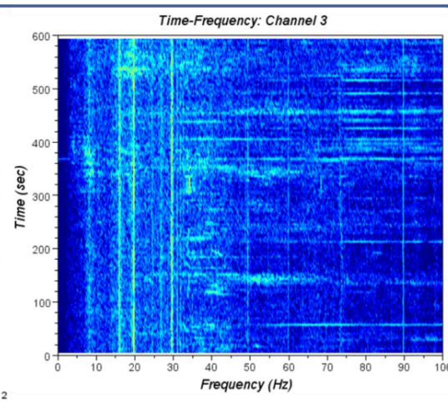

Room: A1188
Equip: 11570A
Findings:
Floor sanding during data acquisition. Vibration easily satisfies spec.



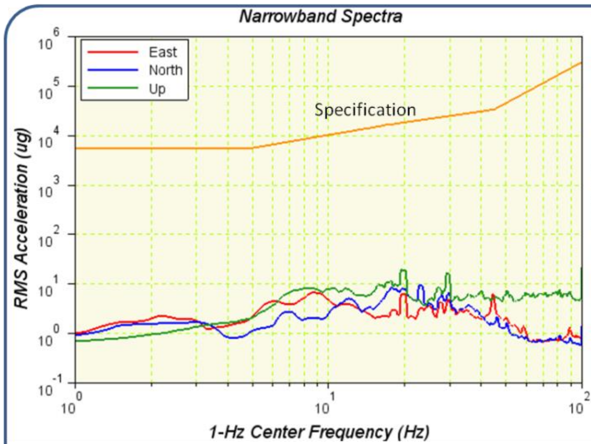

Room: A2103
Equip: 20636
Findings:
Use OR spec. East channel has broken cable. Vibration easily meets spec.

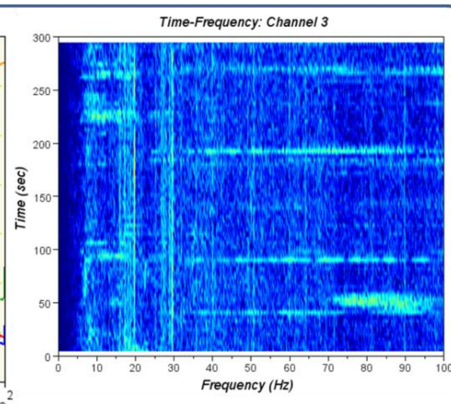


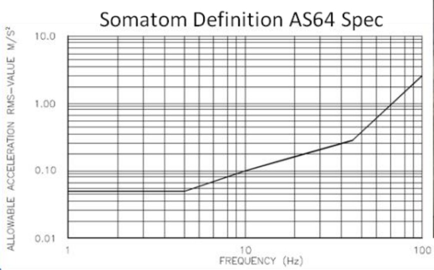




This area of the building encompasses 6 PET/CT scanning rooms: A2139, A2142, A2144, A2147, A2149, and A2152. Data were collected in A2139 and A2149 and sufficiently represent the vibration in all of these co-located and identically-constructed rooms.

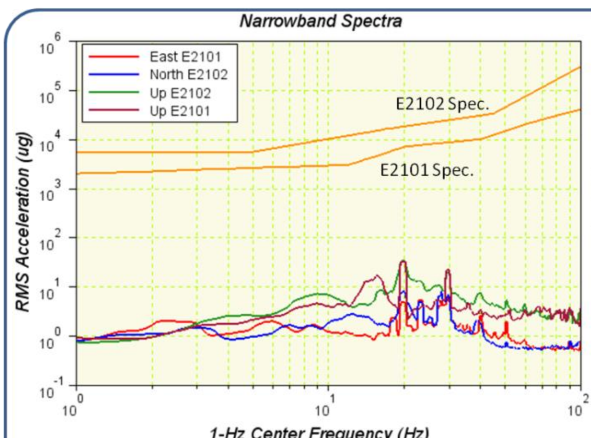
Room: A2139-A2152
Equip: 24713
Findings:
Use OR spec. Broken cable for East channel. Vibration meets spec.

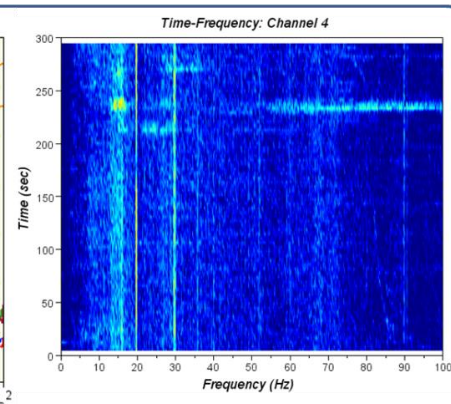


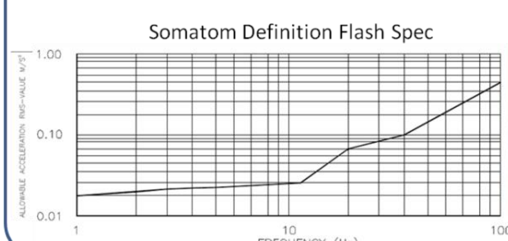



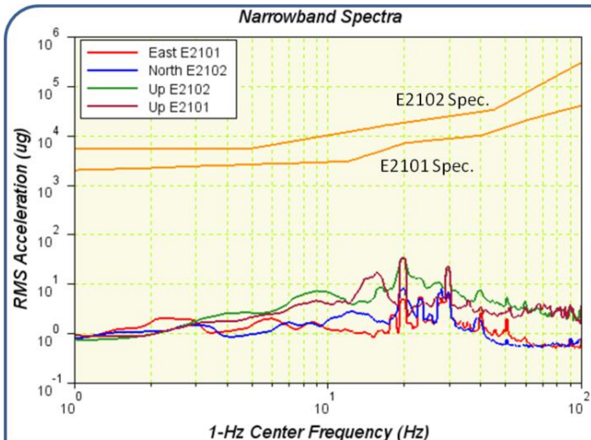

Room: A2191
Equip: 11570A
Findings:
Measured vibration very far below allowed level

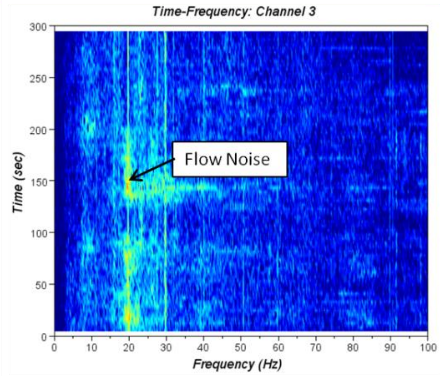


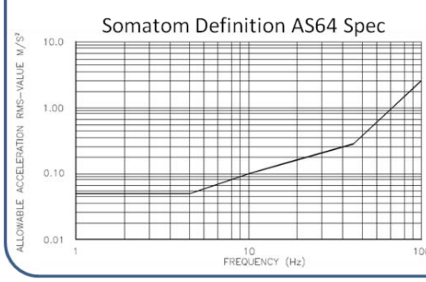



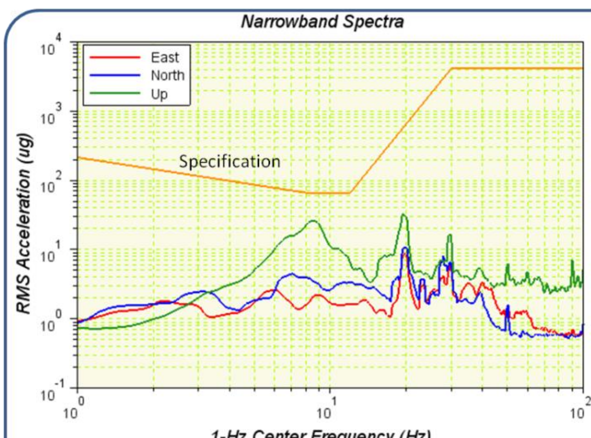

Room: E2101
Equip: 16508A
Findings:
Flow noise that occurred in E2102 was not present during E2101. Vibration satisfies specification.

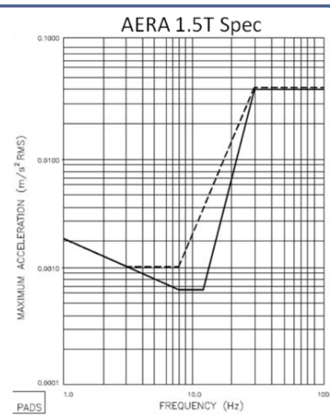


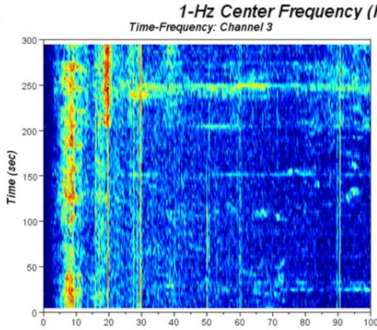



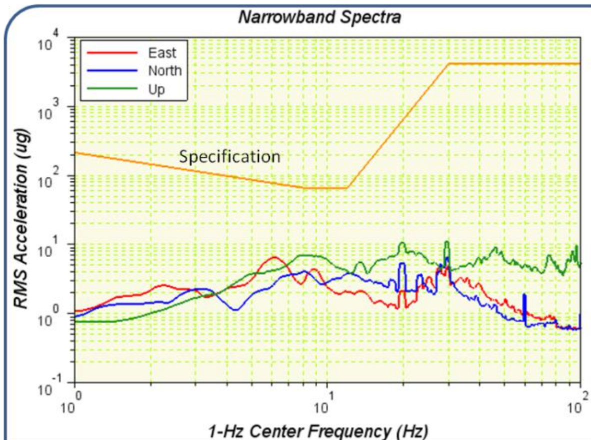

Room: E2102
Equip: 11570A
Findings:
Flow noise that occurred in E2102 was not present during E2101. Vibration satisfies specification.

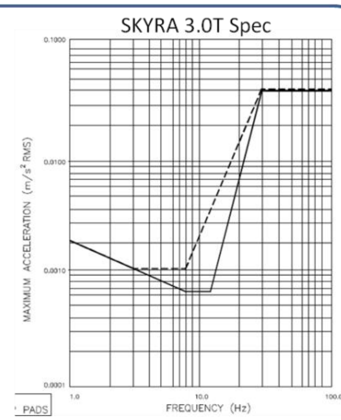


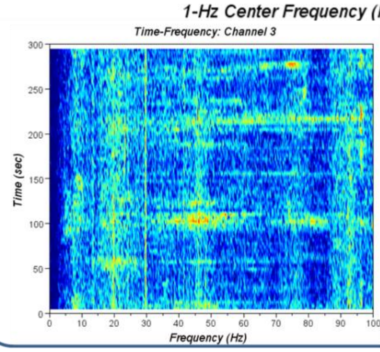



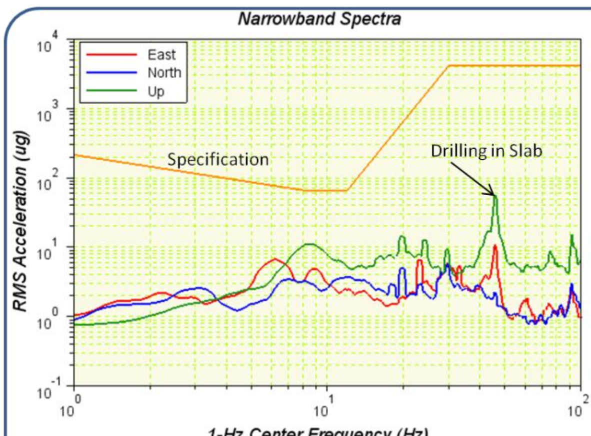

Room: E2122
Equip: 28101A
Findings:
Measured vibration includes some construction noise and meets the requirement

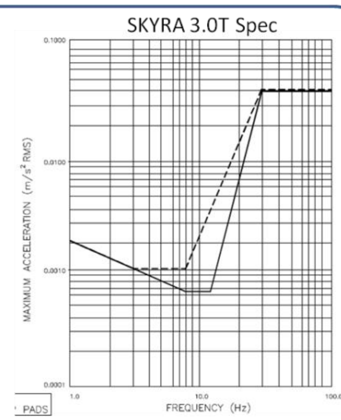


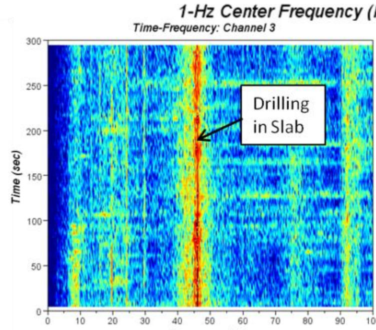



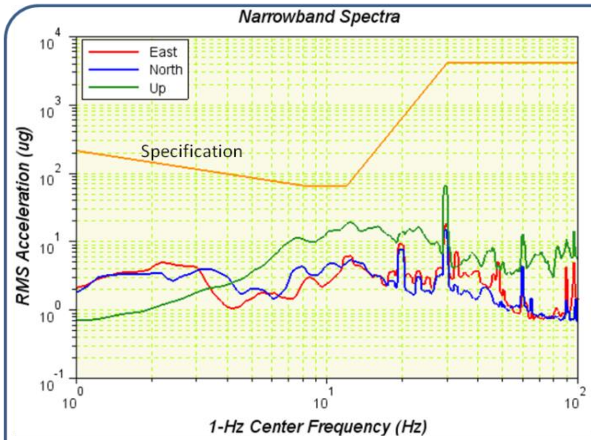

Room: E2124
Equip: 16880A
Findings:
Measured vibration includes some construction noise and meets the requirement

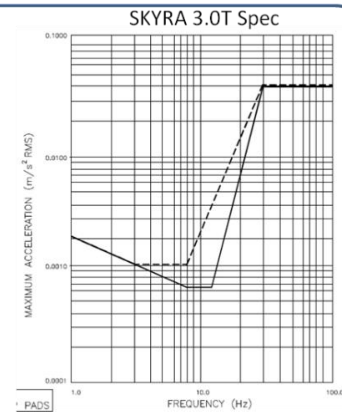


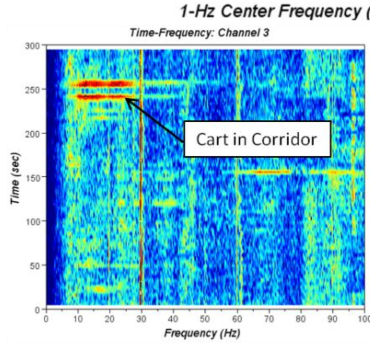



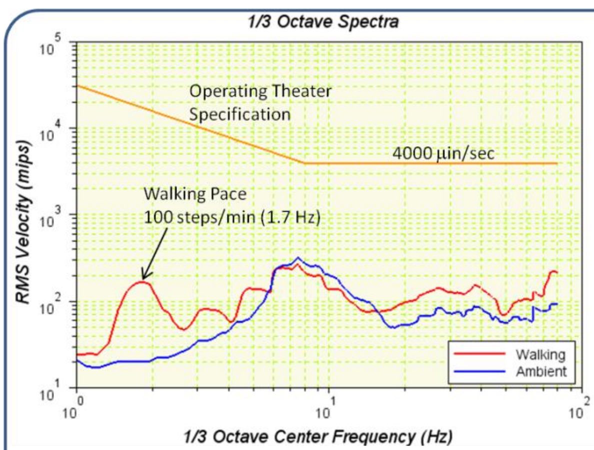

Room: E2129
Equip: 16880A
Findings:
Measured vibration includes construction noise and still meets requirements

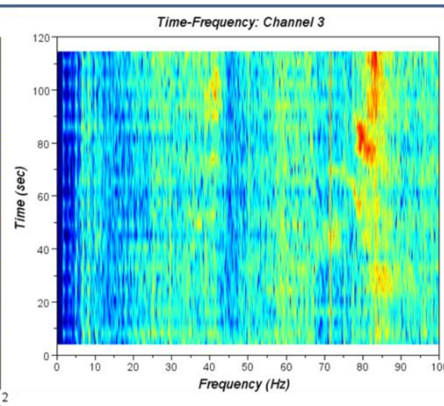


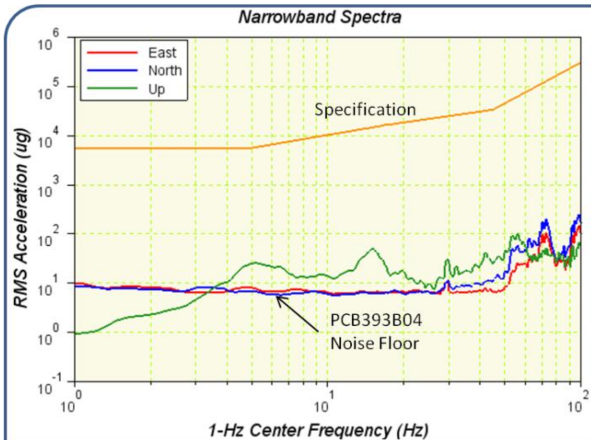



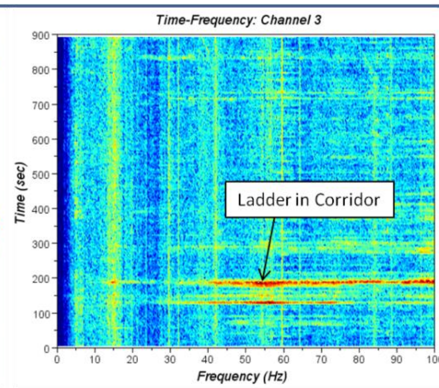

Room: E4193
Equip: 16880A
Findings:
Measured vibration satisfies equipment specification

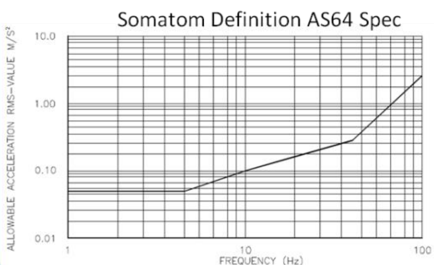



Room: C4C01
Equip: OR
Findings:
Data acquired while walking at 100 steps per min—satisfies OR specification (< 4000 mips)




Room: D16119
Equip: 11570A
Findings:
Hallway activity but measured vibration easily satisfies the spec.

# Section 7

## APPENDIX B: POST-INSTALLATION VERIFICATION

(This appendix is currently blank. The vibration environment will be measured once the MRIs are installed in E2122, E2124, E2129, and E4193.)