Concrete pier foundation and building design for electron microscope installations with vibration disturbances from train, truck, and bus traffic

Chad N. Himmel
Affiliation: JEAcoustics, 1705 W. Koenig Lane, Austin, Texas, USA
e-mail: himmel<at>jeacoustics.com

Abstract
A university microscopy and imaging center housing nine instruments including scanning electron microscopes (SEM) and transmission electron microscopes (TEM) was proposed for a site near an active railroad and roadways. On-site spectrum measurements were conducted to determine the ambient and transient ground borne vibration conditions. Measurements showed that disturbances from trains as well as bus and truck traffic on campus roads significantly exceeded allowable floor vibration tolerances for many of the instruments. This paper addresses the potential for concrete pier-supported floor vibration and structural resonance contributions to ground borne vibration levels and solutions proposed to mitigate the disturbances for sensitive instrument installations.

Keywords: vibration, damping, foundation, pier, microscope

1 Introduction

Electron microscopes can be affected by airborne sound levels and building floor vibration if the disturbance is great enough. Loud low frequency airborne sound levels may induce vibration into lightweight structures, and building floor vibration may transmit to disturb electron microscopes. While an electron microscope is being used, vibration may disturb the specimen or it may disturb the stage where the specimen is placed, or it may cause differential movements between the electron beam projector and the specimen, resulting in image jitter or blur. Manufacturers of electron microscopes provide criteria for allowable floor vibration and airborne noise as a basis for evaluating proposed sites for microscopes prior to their installation. It is necessary, therefore, to consider low frequency sound and vibration in the design and selection of sites of electron microscope installations.
An existing Microscopy and Imaging Center at Texas A&M University was to be moved from a relatively quiet area of the main campus into a new building that would be built approximately 400 meters away. The new building would be located on a site surrounded by roads traveled regularly by University buses and delivery trucks, and within about 200 meters of a busy four-lane road and an active railroad, carrying mixed freight. Figure 1, a vicinity map, shows the proposed new building site and surroundings. Low frequency sound and vibration from trains, trucks, and buses could affect the performance and use of electron microscopes in the relocated imaging center, by disturbing the stability and resolution of the specimen’s image. On-site measurements of noise and vibration spectra were conducted to determine the ambient and transient ground borne vibration conditions of the existing facility and the proposed new site. Measurements showed that disturbances from trains as well as bus and truck traffic on campus roads would regularly and significantly exceed allowable floor vibration tolerances for many of the instruments. Soils exhibited response to disturbances at dominant frequencies around the 5 Hz and 10 Hz 1/3-octave bands.

Damped pneumatic vibration isolation systems can provide vibration disturbance control and damping. The new building foundation design needed to accommodate space for such isolation systems. In addition, it was important that the building foundation would not amplify ground vibration, or exacerbate the vibration disturbances recorded at the site.

2 Criteria and design parameters

2.1 Microscopes

The University had selected various imaging instruments to move to the new building, plus new instruments that would be purchased to occupy the new building. In all, there would be about seven scanning electron microscopes (SEM) and one transmission electron
microscope (TEM). Plus, there would be confocal microscopes, a two-photon laser scanning microscope, and other imaging equipment. The results of on-site measurements were compared to the various criteria available from SEM and TEM manufacturers for the selected instruments. Manufacturers’ proprietary criteria are not disclosed here. The criteria collectively are similar to an allowance of no more than 3 micron/sec RMS constant velocity, shown in Figure 2, and used here to represent the imaging center’s generic floor vibration tolerance.

Figure 2 – Pre-construction maximum vertical (left) and horizontal (right) vibration at soil surface without trains, trucks, or buses passing, compared to representative generic instrument floor vibration tolerance.

2.2 Ground borne vibration disturbances

Ambient and transient ground surface vibration spectrum measurements were conducted on the building site during early design phases, prior to construction. The photograph in Figure 3 shows one of the measurement locations, where simultaneous readings were taken at the surfaces of the soil and a concrete sidewalk near the central bus route. Petro wax was used to mount the transducer to concrete surface; gravity was relied upon for mounting at soil surface. Typical ambient vibration levels at the soil surface without significant disturbances from passing trains, trucks or buses are shown in Figure 2, about 4 dB below the tolerance line. Transient ground borne vibration disturbances from passing trains, trucks, and buses were also measured on site and compared with instrument vibration tolerances. Spectrum results are shown in Figures 5 and 6, with disturbance levels up to more than 20 dB above the generic tolerance line.
Figure 3 – Photo of one of the four pre-construction ground borne vibration measurement locations, with transducers set on surface of concrete sidewalk (bottom left) and on surface of bare soil (top right).

Figure 4 – Photo near the same location in Figure 3, showing the completed building (right) and paved bus route (left), looking towards the 4-lane road and train tracks beyond.
2.3 Soils and foundation type

Soils at the site are very expansive, stiff clay soils. [1] Most of the building foundation was designed to include drilled concrete piers bearing at a depth of approximately 7 meters below existing grade, supporting a 300 mm thick concrete slab above, with a crawlspace about 2 meters in height. Concrete slabs at laboratories would typically have two-way reinforcement. The piers and columns typically would be spaced 6 to 9 meters.

3 Concrete foundation design

Given the unchangeable and challenging ground borne vibration disturbances at the site, it was necessary to consider supporting each of the sensitive instruments on individual vibration isolated bases to achieve manufacturers’ environmental criteria for microscope installations. [2] However, with the building and microscopes supported on a column-
supported slab above a crawlspace, there was concern that the horizontal and vertical ground borne vibration at low frequencies, below 20 Hz, could be amplified significantly as a result of un-damped resonant characteristics of the piers, columns, and slabs. To ensure that the building would not significantly amplify ground borne vibration, and with hopes to possibly attenuate vibration in the imaging center structure, measures were implemented to stiffen and damp various structural elements of the ground floor slab and foundation.

Figure 7 – Structural plan of piers at crawlspace, showing intermediate piers added (blue) for structural floor stiffening.

Figure 8 – Structural plans of piers (left) and columns (right) at recessed floor area, showing intermediate piers and columns added for structural floor stiffening.

To stiffen the structure under microscopes, piers and columns were added at mid-bay locations, or on column-line diagonals, as shown in Figures 7 and 8, so that slabs would span only about 3 to 6 meters rather than 6 to 9 meters. In addition, a vertical recess was needed for electron microscope labs, such that vibration isolation bases (i.e., inertia bases on pneumatic isolation mounts with active or semi-active damping) could be installed underneath microscopes. With isolation bases and pads surrounded by a raised floor system, it would be possible to keep the lab floors and the instrument feet at the same elevation as the main floor surface, as shown in Figure 9. It was hoped the perimeter “walls” of the recessed slab would act like deep beams or shear walls, further stiffening the system.
Vibration isolation bases for the individual microscopes should provide significant attenuation of dominant ground borne vibration peaks at 5 Hz and higher. Base isolators were selected for the particular instruments to be isolated, to have semi-active damping and peak transmissibility at less than 0.8 Hz or less than 1.6 Hz shown conceptually in Figure 10, in order to keep transmissibility amplification limited to frequencies below problematic ground borne disturbance peak frequencies. Damped concrete (i.e., a liquid copolymer concrete admixture) was recommended for the recessed slab, and it was considered in design but ultimately was not implemented by the owner because of concerns regarding reduced concrete strength and a preference to avoid multiple concrete pours. [3]
4 Post-construction performance validation measurements

Ambient and transient vibration spectrum measurements at the recessed slab surface were conducted after construction was substantially complete, when building systems were balanced and operating at full capacity, on a weekday with normal buses, local truck traffic, and trains running. The photos in Figure 11 show one of the indoor measurement locations. Isolation bases for electron microscopes were installed, but the pneumatic isolators were not yet operational, and the bases were still shimmed tight against the recessed floor slab. The building was not yet occupied, and users’ microscopes and furniture were not installed. Therefore, results show slab vibration with some damping effects from dead load and from loads of instrument base and raised floor systems, but not all live-load damping is represented. Added load from heavy microscopy instruments can be expected to provide additional damping. [4]

Results indicate typical ambient vibration level at the recessed slab has a pronounced peak around the 10 Hz 1/3-octave band, shown in Figure 12. That peak is more pronounced and slightly higher than pre-construction soil surface levels at that same frequency. This is likely because soils include damping [5] that is absent in the foundation supported on piers above grade. Also, in the building foundation we have un-damped inherent slab resonances that appear in narrowband measurement results with repeated heel drop impacts to be around 9.5 Hz and 19 Hz. [6] Transient vibration disturbances from passing trains, trucks, and buses were also measured on recessed slabs and compared with instrument vibration tolerances. Spectrum results are shown in Figures 13 and 14, with disturbance levels up to more than 20 dB above the tolerance line.
Figure 12 – Post-construction maximum vertical (left) and horizontal (right) vibration at recessed slab surface without trains, trucks, or buses passing, compared to representative generic instrument floor vibration tolerance.

Figure 13 – Post-construction maximum vertical (left) and horizontal (right) vibration at recessed slab surface with trains passing.

Figure 14 – Post-construction maximum vertical (left) and horizontal (right) vibration at recessed slab surface with buses and medium trucks passing.
5 Conclusions

Ground borne train, bus, and truck vibration disturbances in the vertical direction appear to transmit with little attenuation from soils into the building structure at the ground floor. Measures implemented in building structural design to curtail amplification of that ground borne vibration do appear to have at least kept the anticipated amplification from vertical and horizontal building resonances to a minimum, with some attenuation apparent in the horizontal direction. Apparent horizontal attenuation could also be a result of different mounting phenomena at soil surface compared to recessed floor slab surface. While the post-construction ambient floor vibration peak at the 10 Hz 1/3-octave band is typically more pronounced than at pre-construction soil surface, the level of disturbance from buses and trucks at that same frequency band is slightly less overall than was measured at the soil surface before construction. Vertical train vibration disturbance levels on the recessed slab are about the same as were measured at the soil surface. Thus, isolation systems with semi-active damping appear to have an adequate stage for achieving instrument tolerances for installations. Fully active damping or cancellation systems could still be implemented to ensure disturbances do not affect future, more sensitive installations or longer-term imaging uses. For future similar installations, the addition of a damping admixture in a topping slab within the recessed area would be considered to slightly “smooth off” the most prominent vibration peaks.

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References


