Vibration Control in Labs: How Quiet Can You Get?

To enable small-scale measurement, one lab's solution is to support its concrete platform on a cushion of air.

Last year, Lowell Howard, an electrical engineer at the National Institute of Standards & Technology, Gaithersburg, Md., was able to measure a force to an accuracy of 10 nanonewton. "This kind of sensitivity would be impossible without our new vibration isolation slab," says Clayton Teague, who heads NIST's Nano-Scale Metrology Group. "You could never get these measurements in a typical lab."

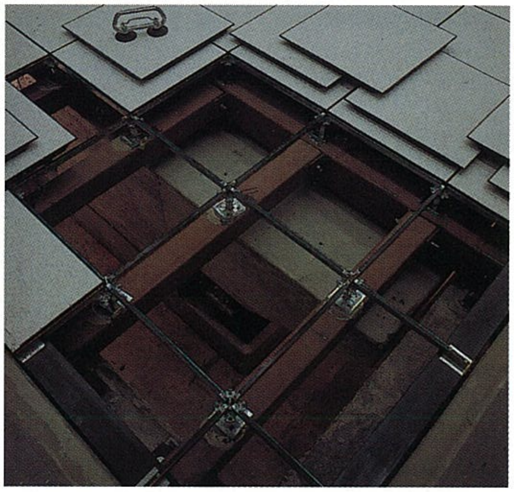
In several areas of R&D—among them microelectronics, microbiology, metrology, lasers, and low-temperature physics—vibration often limits what scientists can do. The good news is that scientists like Howard and Teague aren't letting a little vibration shake them up.

Vibration isolation science At the same time that industry has moved to more sensitive techniques and analytical equipment, lab design has also progressed. The largely empirical parameters used a mere 10 years ago have been replaced by measurements and analytical models that can accurately predict a building's behavior.

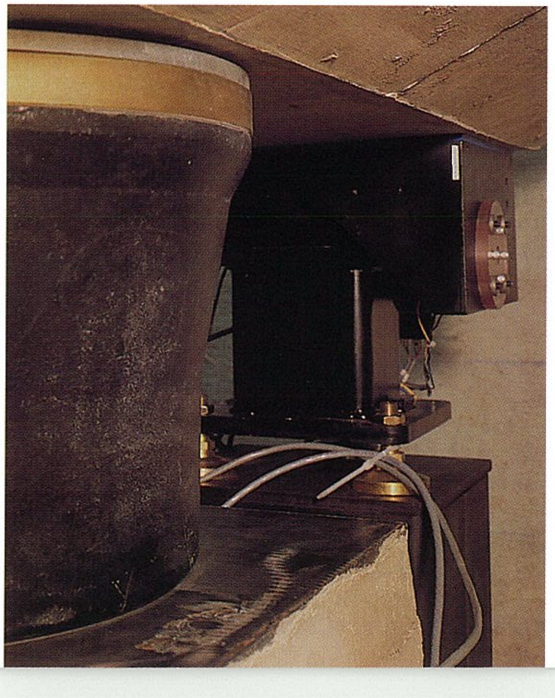
Vibration site surveys are now used routinely to qualify sites for highly sensitive R&D and manufacturing buildings. From a set of measurements, a vibration consultant can identify the sources of vibration and the variation in intensity throughout the day. The most common vibration sources are external car, truck, or train traffic, but sometimes the main problem is internal and can be remedied—for example, a compressor in the central plant that has become unbalanced or is not properly isolated.

The same vibration-testing equipment can be used inside buildings to identify sources of vibration and to find the best locations for sensitive equipment. An afternoon spent testing a few labs can save thousands of dollars in future relocation costs.

Architectural design can go a long way toward producing quiet buildings. Ideally, sources of noise and vibration—particularly chillers and emergency generators—should not be placed within the same structure as labs. The creative use of expansion joints can serve a triple purpose here: alleviating thermal stress, improving seismic performance, and reducing vibration caused by building equipment. Isolation joints alone will not be sufficient to cancel all vibration transmission. Low-frequency disturbances readily travel through the foundation and soil around the isolation joint.



With walk-on floor tiles removed, the NIST isolation slab is easily visible. *(all photos: HDR/Alan Karchmer, photographer)*



The air pistons supporting the isolation slab are large-scale adaptations of the technology used in conventional optical tables.

An indispensable level of protection comes from vibration-isolation springs, which are integrated into the supports of mechanical and electrical equipment in single or double sets. Their properties can now be calculated and matched to the weight and RPM of the equipment. In highly sensitive facilities, spring-isolated hangers can be used for piping and duct work.

Sound and vibration can also be dampened in air-handling systems by designing duct work for low air speeds and adding sound attenuation to air-handling units.

Using measurements, computer models, and isolation techniques, design teams have been able to produce buildings with excellent vibration characteristics.

If the second floor of a typical office building shows vibration velocity amplitudes of 300 μm/sec, the same floor in a well-designed university lab building can achieve 10 μm/sec to 12 μm/sec without a substantial increase in overall cost. Typical microelectronics facilities have floors that can achieve 3μm/sec to 6 μm/sec at a few hundred dollars/ft^2.

The quietest place in any structure is the slab-on-grade. Its performance is essentially the same as the ground underneath. On a typical suburban or rural site where heavy ground or air traffic is not a factor, vibration amplitudes fall to just 3 μm/sec or less. This low level represents the long-wave background vibration present almost anywhere on earth.

Prototype design But what if even the quietest slab-on-grade is not good enough?

NIST's Teague and his colleagues, expecting to work at accuracies below 1 nm, needed an environment with significantly reduced background vibration. An air-supported platform was proposed as part of the design of a new lab building. To test the concept, a prototype was built in an existing lab on NIST's campus.

The design consists of a massive concrete slab supported on air pistons. Since the concrete mass literally floats on a cushion of air, most ground vibrations are canceled out.

The slab, which has a heavy concrete keel, measures about 13 ft × 33 ft, large enough to accommodate two experiments aligned with each other. It is supported by 10 airsprings, five on each side. In its inactive state, the slab rests on a concrete base. As the airsprings are inflated, the slab is lifted about ⅜ in off the base.

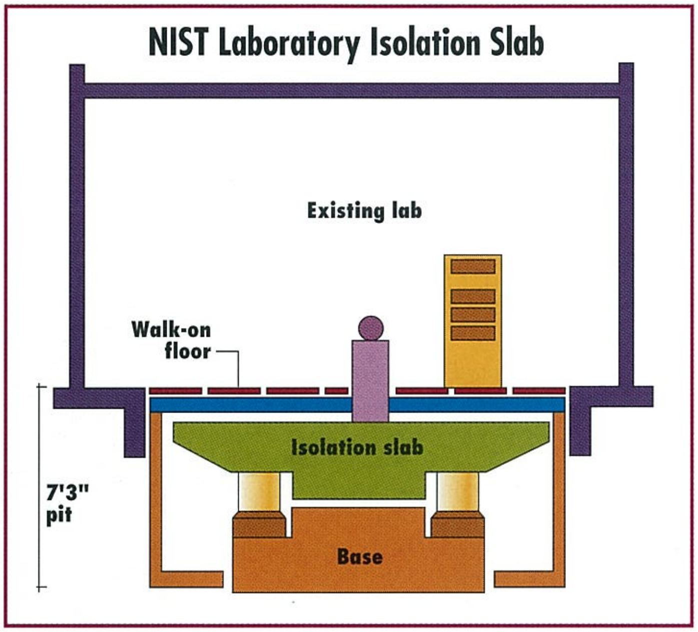
Only the vibration-sensitive components of an experiment are mounted on the isolation slab. Above the slab is an independently supported "walk-on floor" for foot traffic and for placement of supplemental equipment.

Scientists and the designers of the prototype agreed to a performance goal of vibration velocity amplitude of 0.75 μm/sec or less in the frequencies between 8 Hz and 100 Hz. This is about four times lower than the velocity measured on the slab-on-grade below the existing lab.

It came as a pleasant surprise that initial tests showed the slab performing at less than 0.2 μm/sec above 5 Hz—more than an order of magnitude better than what is possible on a slab-on-grade.

Design improvements The tests also provided insight into the behavioral mechanics of the system, leading to further improvements.

As predicted by calculations, relatively high levels of velocity were measured at 1.4 Hz, the resonant frequency of the air springs. Two other peaks measuring 1.7 and 0.4 μm/sec, at 3 and 4 Hz respectively, did not show up in theoretical models, but may have been caused by horizontal rocking of the system. The addition of an active control system for the air springs reduced all vibration transmission below 4 Hz by 50%.



This cross section shows how air pistons *(yellow cylinders)* support the concrete slab, while the walk-on floor framing *(blue)* rests on the walls of the existing pit. *(Source: HDR)*

Structural problems with the walk-on floor system—which also exhibited a troublesome ringing sound—were apparent in the first tests. The floor's framing was rigidly connected to the wall below, and lightweight-aluminum access floor panels were used for the surface. Tests showed that footfall on the floor was readily transmitted through the building structure and surrounding soil into the foundation of the isolation slab and, to some extent, through the springs.

Although no one was likely to walk on the floor while sensitive measurements were in progress, there was always the chance that electronic equipment crowded on the floor could be a source of vibration.

Vibration and acoustic performance improved dramatically after neoprene bearing pads were inserted under the steel beams and the aluminum floor panels were replaced with heavier, concrete-filled versions.

—Bea Sennewald, AIA, and Hal Amick, P.E.

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Reprinted from **RESEARCH & DEVELOPMENT** March, 1996