No Such Thing as "Good

Vibrations” in Science

By Franklin D. Lancaster, P.E., RA, LEED AP, F.ASCE

A facilities manager must ensure that a building runs as smoothly and successfully as possible. For college, university, and school managers dealing with laboratories and other spaces for scientific study and research, this means making sure that nothing disrupts experiments and other scientific endeavors. Such disruptions can wreak havoc, negatively impacting research or funding.

Vibrations caused by mechanical equipment, by people walking across a floor, or by outside traffic can be annoying to the occupants of any type of building. Vibrations in laboratory buildings, however, can be more than just annoying – they can interfere with sensitive equipment, ruin experiments, and affect the behavior of laboratory animals.

Campus facilities managers must understand the impact of vibrations on science buildings, and work with their architects and engineers to establish what special measures must be taken to ensure that laboratories resist vibration problems. Design considerations include tailoring architectural, structural, and mechanical elements for the needs of laboratory buildings, and simply planning spaces with vibration in mind.

Higher strength steel and lighter weight materials allow longer spans in modern buildings, making proper design for vibration even more important. But model codes, such as the International Building Code (IBC), which governs the design of most buildings in the United States, only address building structures from a strength standpoint. They provide little information regarding serviceability issues like vibration. In fact, according to one structural engineering standard referenced by the IBC, “Serviceability limit states involve the perceptions and expectations of the owner or user and are a contractual matter between the owner or user and the designer and builder. It is for these reasons, and because the benefits are often subjective and difficult to define or quantify, that serviceability limit states for the most part are not included within the model United States Building Codes.” A strength limit states failure of a beam or floor slab means the floor would collapse. A serviceability limit states failure means the floor would vibrate excessively, making it unusable for its intended purpose. Facilities managers and designers must collaborate effectively to prevent both types of failures.

VIBRATION FACTORS

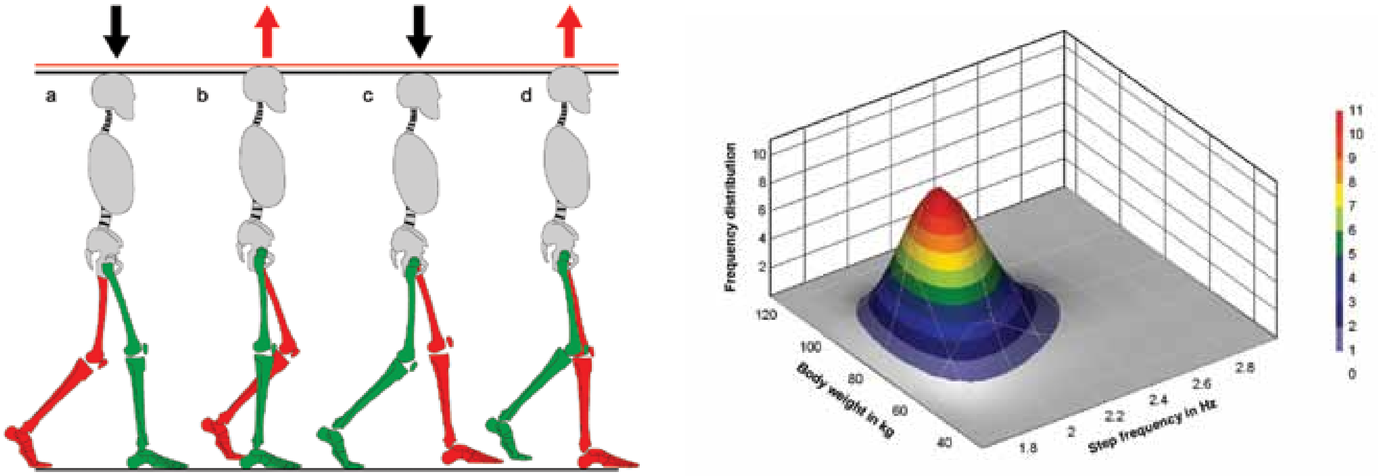
The three primary factors involved in assessing a vibration problem are the vibration source, transmission path, and the receiver. Vibration comes from a wide variety of sources, including mechanical equipment operating within the building; ground-borne vibrations from cars, trains, and subways; airborne noise from airplanes, speech, or music; and footfall traffic on supported floors. The transmission path represents all of the elements that vibrations must travel through, and may include soil supporting a building, the building foundations, columns, walls, and floor slabs. The receiver is what is ultimately affected by vibrations, and could consist of building occupants (human or animal) and instruments such as microscopes or sensitive scales. The key to mitigating vibration problems begins with understanding these factors, and knowing how to adjust design practices and construction methods for specific science building uses.

Sometimes, solving a vibration problem is as simple as increasing the distance between a vibration source and receiver. However, this is not always possible. For example, at the unified science center at the University of Scranton, a Jesuit university in Scranton, Pennsylvania, the available site placed the new building less than 100 feet from active railroad tracks. To assess the impact of the passing trains on the proposed building, consultants took vibration measurements at various places on site over a period of time. This testing helped the design team consider several mitigation factors, such as the effect of a mat foundation, use of a concrete structure for the second floor, and detailing sound-deadening exterior walls.

Although all sources of vibration must be considered, by far the most significant cause of problems in laboratory buildings stems from foot traffic. An early method of assessing the response of a floor to walking was the Heel


HEAVY FOUNDATION NEAR TRAIN TRACKS, UNIVERSITY OF SCRANTON


MICROSCOPE LAB, PHOTO CREDIT: MICHAEL MORAN



HUMAN INDUCED VIBRATION, PROBABILISTIC METHOD

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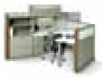
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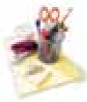
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Drop Test. In this test, a person stands in the middle of a room, rises up on his toes, and drops his weight through his heels to the floor. The floor response can be felt and classified on a scale from "not perceptible" through "distinctly perceptible." More current study stems from the European Commission Joint Research Centre's "Design of Floor Structures for Human Induced Vibrations," which presents a more refined probabilistic method considering body weight and step frequency. Such publications illustrate that a great deal of research has been conducted around the world to deal with designing floors to support a walking person.

FLOOR VIBRATION

In 1828, English engineer Thomas Tredgold wrote, "Girders for long bearings should always be made as deep as they can be got; an inch or two taken from the height of a room is of little consequence compared with a ceiling disfigured with cracks, besides the inconvenience of not being able to move on the floor without shaking every thing in the room." In general, the same principles apply today.

Many laboratory buildings consist of steel frame construction with floors of steel beams supporting concrete slabs on metal deck. Floor beams in such an assembly vibrate at a natural frequency when an impact force is applied. This frequency depends upon the beam span, spacing between beams, and depth – properties that affect the stiffness of the beams. Methods to calculate the frequency of floor framing systems are presented in publications such as the American Institute of Steel Construction (AISC) Steel Design Guide 11, "Floor Vibrations Due to Human Activity," and can serve as a starting point when discussing target floor vibration criteria.

ISOLATED STUDIO, THE COLLEGE OF NEW JERSEY

Vibration perceived by building occupants is mitigated by damping, which acts to reduce the energy in a vibrating system. Damping in floor systems is provided by the self-weight of the floor as well as superimposed loads such as partitions and millwork. Understanding the concepts of stiffness and damping allows designers to incorporate low-cost vibration mitigation elements into the building during the early planning phase.

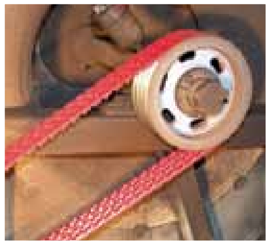
LAYOUT AND PLANNING

Corridors:

The simple act of walking can produce troublesome vibrations within a bay of floor framing. In a typical building with a central corridor and rooms on both sides, it is structurally efficient to place columns along only one side of the corridor. This results in a long span from the corridor line of columns to the farthest exterior wall. The long span supports both the rooms and the corridor, and vibrations caused by footfall traffic in the corridor directly transmit into the rooms sharing the corridor support beams.

In order to mitigate this problem, place columns along both sides of the corridor. Although this requires additional columns and foundations, isolating corridor traffic with separate framing prevents vibrations from propagating into adjacent spaces. Furthermore, the shallower members that span the short corridor provide extra depth for utilities that compete for limited space above corridor ceilings.

Another consideration for corridor design is the speed at which people walk. A fast-walking person generates vibration velocities 15 times greater than that of a person walking slowly. Therefore, try to arrange corridors in ways that discourage fast walking, such as making them shorter or interrupting them with turns. If this is not feasible, incorporate visual breaks in floor patterns and lighting, and emphasize aesthetically pleasing interior design in corridors. People tend not to rush through pleasant spaces as fast as they would through unpleasant ones, which calms traffic.



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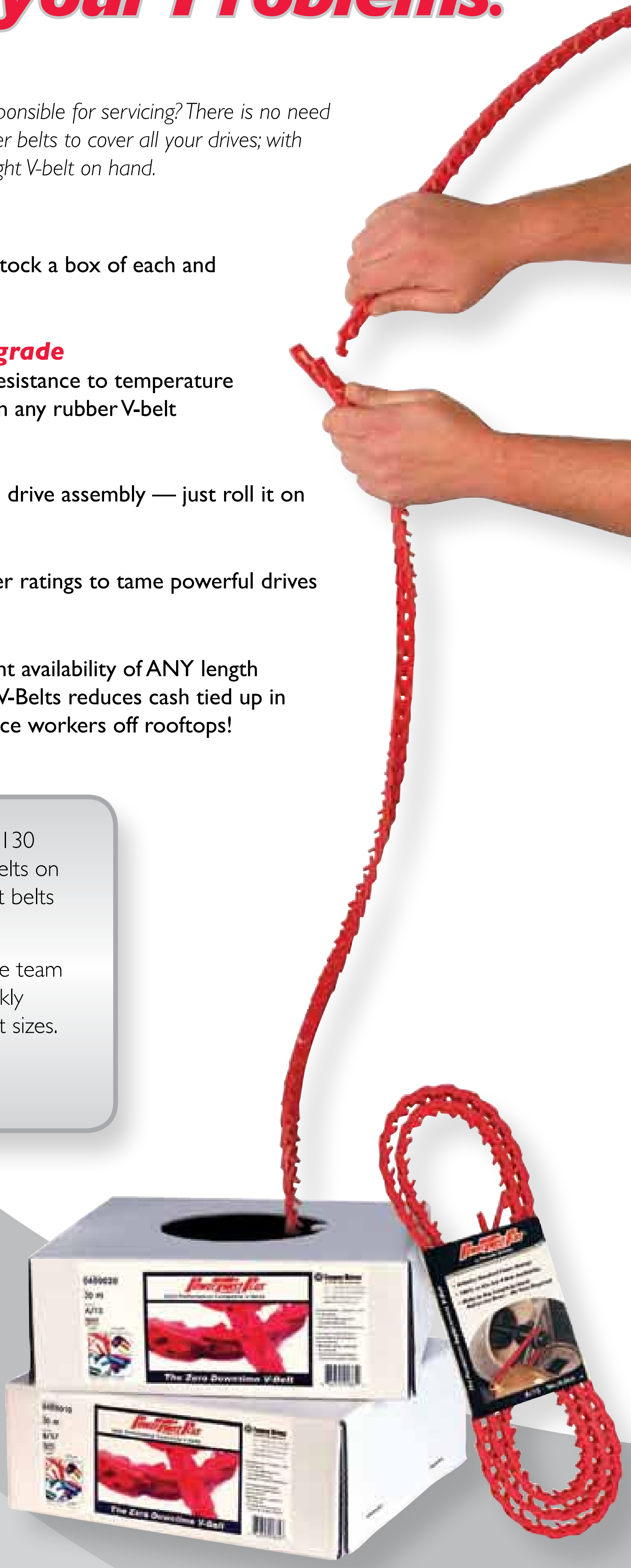

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Span:

Bay size plays a critical factor in the vibration characteristics of a floor system. Since the stiffness of a beam varies as its length raised to the third power, shortening the span is an effective way to improve its vibration behavior. Even though we have the technology to span long distances with high-strength members, laboratory buildings benefit from closer column spacing.

Note that not all spans in a building must be short. Designating sensitive equipment zones can provide vibration-safe areas that maintain a certain amount of flexibility for moving equipment within the zones, without penalizing the entire structure with closer column spacing everywhere. Similarly, not all floor framing systems must satisfy the most stringent equipment requirements. Criteria is available that categorizes sensitivity to vibration based upon type of equipment, such as magnification power of microscopes, and can help the structural engineer finetune spaces for known uses.

INERTIA BASE SUSPENDED WITH ELASTIC STRAPS

Mass:

The mass of floor slabs affects the vibration characteristics of a space. High-rise office building floors often consist of lightweight concrete supported by metal deck and steel framing. Lightweight concrete is made with stone expanded in a kiln, and weighs only 115 pounds per cubic foot (pcf). By comparison, normal-weight concrete weighs 150 pcf. Using lightweight concrete allows the use of lighter beams, and can reduce the size of foundations. However, laboratory buildings benefit from the enhanced damping effect provided by normal-weight concrete; and the thicker the slab, the better vibration properties of the floor system.

The College of New Jersey Art and Interactive Multimedia Building, Ewing, New Jersey, provides an example of successful manipulation of slab thicknesses to achieve vibration performance goals. After mapping the locations of noisy mechanical equipment above quiet spaces, varying slab thicknesses were used to provide appropriate acoustical separation.

Layout:

A footfall impact at a beam's midspan produces greater vibration than the same impact near a column. Furthermore, vibrations dissipate as they cross column lines, walls, and framing. Consequently, sensitive equipment placed close to columns and far away from corridors will perform better than equipment placed near bay centers and close to sources of excitation. From an overall planning perspective, hold early discussions to identify critical equipment or functions, and decide their appropriate locations within the building. For example, particularly sensitive equipment should occupy isolated slab-on-grade space rather than an elevated slab level.

Floor Isolation:

One method of isolating a portion of a floor is constructing a room within a room. A secondary slab floating on neoprene pads above the base structural slab provides effective isolation of discrete areas. Combined with properly detailed walls and an independent ceiling structure, this type of construction creates a well-protected shell. However, the base structural slab must still meet basic deflection limits, and the frequencies of the intended isolation must be determined. This type of construction typically involves an acoustical consultant.

Mechanical Equipment Isolation:

Modern installations of mechanical equipment include vibration isolators, flexible couplings, and resilient hangers designed to prevent transmission of equipment vibration into the structure. These are typically designed by the equipment manufacturer, and not the project engineer. However, those reviewing these elements during construction should be able to recognize improperly installed or overloaded isolators. Spring isolators should not be fully compressed, elements on either side of flexible couplings should be independently supported, and rigid connectors should not bridge between isolated elements.

Sensitive Equipment Isolation:

Some laboratory equipment comes with its own isolation system designed to prevent transmission of structure-borne vibrations into the equipment. Many of these systems include some type of inertia damper, and the structure must be designed for the additional weight.

Commissioning:

More and more building owners realize the many benefits of commissioning, particularly with the demand for achiev-

SPRING ISOLATOR SHORT CIRCUIT

ing LEED™ certification. The intent of commissioning is to verify and ensure that fundamental building elements and systems are designed, installed, and calibrated to operate as intended. Discovering improperly installed or short-circuited isolation devices during the commissioning process can avoid complaints from users and potential equipment damage. In one instance, a check of a spring-isolated equipment pad revealed that concrete was accidentally placed between the pad and the supporting floor slab, rendering the springs useless. If not corrected, vibrations from the motor mounted on the pad would have been directly transmitted into the structure.

CONCLUSION

Vibrations in undergraduate science buildings deserve serious attention from the building owner and design team. This article points out many mitigation measures, such as properly locating vibration-sensitive equipment away from sources of excitation, adjusting column spacing and floor slab thicknesses, and isolating mechanical equipment.

However, the most critical factor to ensure the design of a building that successfully addresses vibration issues is a strong relationship among the facilities manager, architect, and engineers, where everyone understands vibration concepts, building uses, and performance goals.

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