Subduing Vibration in Laboratory Buildings

By Frank Lancaster, P.E., RA, LEED™ AP

> ***"Strength is essential but otherwise not important."***
>
> ***–Hardy Cross***

This quote from Professor Cross, inventor of the moment distribution method, emphasizes what the world expects from a structural engineer. The public takes for granted that the structural engineer will design building systems of adequate strength to protect the health, safety and well-being of the occupants. As well they should, for the public has the right to demand these basic tenets. But given the expectation that all strength requirements will be met, excellent structural engineering also must consider serviceability issues such as vibration.

Vibrations caused by mechanical equipment, by people walking on a structured floor, or by airborne noise can be annoying to the occupants of any type of building. Vibrations in laboratory buildings can be more than just annoying – they can interfere with sensitive equipment, disrupt experiments, and affect the behavior of laboratory animals.

Higher strength steel and lighter weight materials allow longer spans in modern buildings, making proper design for vibration more important. With critical manufacturing processes, vibration criteria are well defined, and extensive vibration controls are employed to meet those specific criteria. However, general laboratory buildings for most university and research clients do not have specific vibration criteria other than "vibration is an issue."

Steel framed laboratory building; University at Albany Center for Excellence in Cancer Genomics.

For these types of buildings, engineers must take special measures to ensure that the entire structure is more resistant to vibration problems. Design considerations include using heavier concrete floor slabs that provide more damping capacity, placing columns on both sides of corridors to reduce the impact of foot-fall vibrations propagating into adjacent lab spaces, and structurally isolating spaces particularly sensitive to vibration disturbances.

Vibration table used to place vibration sensitive equipment; Rochester Institute of Technology.

Noise Measurements

Understanding common measurements for sound transmission, noise reduction, and impact insulation provides a useful background for vibration design. Each measurement addresses a different concept, and each concept involves various adjustments to construction methods.

The **Sound Transmission Class (STC)** measures the ability of a wall assembly to prevent the transmission of sound from one side of a wall to the other. The higher the number, the less sound can pass through a partition. A typical 4-inch metal stud wall with a layer of 5/8-inch gypsum board on each side offers an STC of 38. Adding fiberglass batt insulation to the wall increases the STC to 43, and increasing the mass by adding a second layer of drywall to both sides increases the STC to 45.

The real trick to improving the STC is to break the pathway by which noise travels through a wall. The most common way to accomplish this is to mount the layer of drywall on one side of the wall on resilient metal clips. The resilient clips absorb airborne vibration, preventing the sound waves from propagating through the structure. This results in an STC of about 52.

Recommended sound isolation between adjacent laboratory spaces is STC 42 to 48. Use caution if designing stud shear walls with gypsum board sheathing, because gypsum board mounted on resilient channels offers no structural capacity.

Lab Space with flexible layout options; University at Albany Center for Excellence in Cancer Genomics

Another method of increasing the STC of a wall assembly is to increase the mass by using concrete masonry units (CMU) or concrete wall panels. An 8-inch solid grouted CMU wall provides an STC of 55.

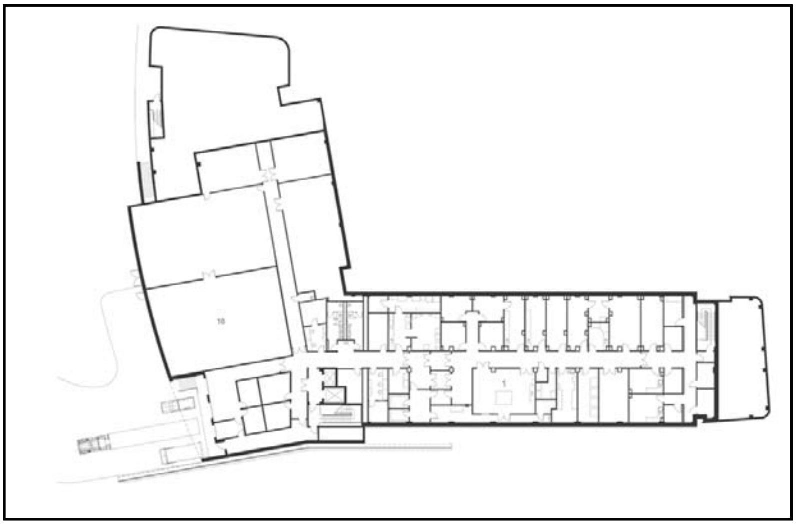
In order to be effective, partitions meant to block sound from traveling to an adjacent space must maintain a complete seal against all edges. This may be difficult at tops of partitions that abut irregular surfaces such as slabs on metal deck, but if not properly sealed, flanking of noise from one space to another can occur. A one-inch square hole through a wall can ruin the STC rating of a rigorously designed assembly. When sealing the top of non-load-bearing partitions, install materials that allow the floor system to deflect without loading the walls. Do not grout the space between the top of a CMU wall and the underside of the floor deck unless the wall is designed to be load-bearing.

Noise Reduction Criteria (NRC) refers to the sound absorption qualities within a space. Noise, defined as unwanted sound, can be controlled within a room by carpeting the floor or installing acoustical ceiling tiles. These materials absorb some frequencies and reduce reverberation.

Note that modifications to room elements to improve the NRC are made to benefit the occupants of the room, and have no effect on the transmission of sound from one space to another. For example, adding an acoustical ceiling in a mechanical room does not effectively shield the occupant in the floor above from noise.

Both the STC and NRC deal with airborne sound, and apply to a limited frequency range found in human speech (125 to 4000 Hz.) As for structure-borne noise, **Impact Insulation Class (IIC)** measures the isolation effectiveness of floor-ceiling assemblies to prevent the transmission of noise created by dropped objects and footfalls from an upper space to a lower space. The IIC measures sound pressure levels over a similar range as the STC (100 to 3150 Hz,) and the higher the IIC, the greater the capacity of the floor to ceiling assembly to prevent transmission of noise.

Construction methods of improving the IIC are similar to improving the STC – provide isolation joints through floor slabs to create breaks in noise pathways, mount ceilings on resilient clips, and caulk all joints. Keep in mind that many of the techniques used to improve isolation of adjacent spaces effectively sever floor diaphragms and shear walls, making close coordination of noise control measures with lateral force resisting systems imperative.



Columns along both sides of the corridor; University at Albany Center for Excellence in Cancer Genomics.

Measurements presented thus far focus on a limited range of frequencies and primarily deal with standard methods of controlling noise transmission between adjacent spaces. While these concepts must be addressed, floor vibration and the prevention of structure-borne noise from multiple sources represent more significant challenges for the design team.

Floor Vibration

Many laboratory buildings we design consist of steel frame construction, with floors of steel beams acting compositely with 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 AISC Steel Design Guide 11, *Floor Vibrations Due to Human Activity*, and most structural analysis programs include vibration algorithms.

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 system, as well as superimposed dead loads such as partitions and millwork. Therefore, the components most under the control of the design engineer are stiffness of the floor beams and mass of the floor slab.

Vibration Sources

Vibration comes from a wide variety of sources including vehicular traffic on adjacent roads, airplanes, footfall traffic on supported floors, and mechanical equipment. The impact resulting from vibrations causes an equally wide variety of problems. For example, while touring a manufacturing plant, we wondered why a lathe operator was staring out the window with tools in hand and the machine running. We learned that she was not daydreaming on the job – she was waiting for a train very close to the building to pass by because the vibrations were strong enough to ruin a delicate process. In addition, we recently completed emergency foundation repairs for an historic building in New York City where vibrations from subway trains contributed to subsidence of soil beneath existing footings. Both of these examples represent serious impacts to productivity and safety by vibration problems.

Although all sources of vibration must be considered, by far the most significant causes of problems in laboratory buildings stem from foot traffic and mechanical equipment. Evaluation of design options, damping, source vibrations, and functions sensitive to vibration disturbance leads to basic layout and planning principles that we follow for all laboratory buildings.

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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 are directly transmitted 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 frame the short corridor span provide extra depth for utilities that compete for precious laboratory plenum space.

Another consideration for corridor design is the speed at which people will walk. The expected vibrational velocity of a floor subject to slow walking is about 1/15 of that for fast walking. 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 that emphasize elements transverse to the length of the corridor. Providing visual variety calms traffic, and people tend not to rush through pleasant spaces as fast as unpleasant ones.

Microscope lab; Hamilton College.

Span

Bay size plays a critical factor in the vibration characteristics of a floor system. Since the stiffness of a beam varies as the cube of its length, shortening the span is a very effective way to adjust its flexibility. 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 and maintain a certain amount of flexibility for moving equipment within the zones, but not penalize 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 equipment, such as magnification power of microscopes; or by use, such as micro-surgery, and can help the structural engineer fine-tune spaces for known uses.

Mass

The mass of floor slabs affects the vibration characteristics of the space. Office building floors often consist of 3¼ inches of light-weight concrete over the metal deck top flutes, yielding a 2-hour fire rating. By comparison, 4½ inches of normal-weight concrete is required over the top flutes of the deck to achieve the same fire rating. Using lightweight concrete allows the use of lighter beams, and can reduce footing sizes. However, laboratory buildings benefit from the enhanced damping effect provided by normal-weight concrete, and its use is standard practice for labs in our office. Even if the building code requires less stringent fire separation and a thinner slab would suffice, constructing a heavier slab improves the performance of the floor system from a vibration perspective.

Layout

A footfall impact at midspan of a beam 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 may want to occupy isolated slab-on-grade space rather than an elevated slab level.

Inertia base suspended with elastic straps; New York University.

Special Considerations

Floor Isolation

As an extension of the concept of separating corridor supports from lab space supports, a walking structure supported independently from the floor framing may provide an increased degree of isolation. Corridor beams that connect only to the columns and not to adjacent floor framing could accomplish this separation.

Another method of isolating an entire floor is constructing a room within a room. A secondary slab floating above the base structural slab on neoprene pads provides effective isolation of discrete areas. Combined with high-STC walls and an independent ceiling structure, this type of construction creates a well-protected shell. However, support of 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, there is a useful concept to know about equipment isolators. Neoprene pads effectively prevent transmission of high-frequency vibrations, such as those produced by a running motor. However, they are ineffective at preventing transmission of low-frequency vibrations such as jolts created when a motor starts and stops. Springs are needed to handle that type of action. Be aware of the limitations of each type of isolator, particularly when troubleshooting.

Sensitive Equipment Isolation

Some laboratory equipment comes standard 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 achieving 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.

Common Sense

Structural engineers have the ability to make just about anything work. We can design an elaborate isolation system allowing the placement of an upper floor eye surgery suite directly next to an aerobics room. But why would we? We have the responsibility to use our Earth's resources and our client's money efficiently. Close cooperation among lab planners, architects, and engineers of all disciplines in an integrated fashion empowers us to subdue vibration problems intelligently as a team.▪

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