MINIMIZE FLOOR VIBRATION PROBLEMS

As structural engineers, we've accepted that the majority of our best work gets hidden behind drywall and above ceilings. However, floors are one area where the occupants of a building interact directly with our structures on a daily basis. A floor that bounces when someone walks by can significantly impact how a person perceives the quality of a building and even affect a worker's efficiency.

Floor vibrations occur because human or mechanical activity resonates with the natural frequency of the floors. While this can cause an uncomfortable sensation to the occupant, it can also interfere with the operation of laboratory or medical equipment sensitive to vibration. The extent that floor vibrations are critical depends upon the use of the space and expectations of the occupants. A person studying in a library will have a different perception of vibrations than a person working out in a gym.

To minimize floor vibrations, during the design process we can evaluate:

1) Changing the frequency of the floor. This can be accomplished by changing bay sizes, increasing the depth of the floor system, or in some cases just by switching the orientation of the framing.
2) Adding weight to the floor. This can be accomplished by thickening a slab, using normal weight instead of lightweight concrete, or if necessary, changing the construction type all together. Increasing the weight of the floor increases the amount of force necessary to excite floor vibrations.
3) Damping the floor. Similar to placing a hand against a ringing wind chime, damping a floor decreases the magnitude of vibrations that have been introduced. Typically this is passively accomplished by architectural components such as ceilings, partition walls, and furniture. Different construction types offer different levels of damping.
4) Isolating the affected area from the rest of the structure. When extreme vibration-producing situations such as running tracks, aerobic studios and dance halls are not on a slab on grade, sometimes the only way to effectively control the vibration is to provide separate framing for the area so that it is completely isolated from the rest of the structure.

Floor vibrations are a larger issue today than ever before. Open floor plans beg for larger bays and wider column spacing, which are more susceptible to vibration problems. More efficient structural designs and stronger construction materials have reduced the weight and size of floor framing. As we move from paper offices to electronic offices, file cabinets, bookshelves, and partition walls are not as prevalent – all items that added weight and helped with damping the floor. With all of these issues, now more than ever, it is important to select a structural engineer who is familiar with floor vibration and to discuss your expectations at the beginning of the project.

As designs have changed, so have the tools we use to analyze vibrations. Many of the older vibration analysis techniques were calibrated to traditional office spaces and are not valid for today's structures. For today's buildings it is important that the structural engineer use the most current analysis techniques.

If floor vibrations are encountered after a floor is constructed, the options for addressing floor vibrations are limited and may be expensive or impractical. If the floor has additional load capacity (often not the case if the cause of vibration problems was a light and efficient floor system to begin with) ballast can be added to the floor. Columns can be added to decrease span lengths. Active damping systems can be used to reduce vibrations but these are very expensive.

About ten years ago we followed the then-current vibration analysis procedure used to design a floor system for a building with an atrium. Those provisions produced a floor without noticeable vibration except at the receptionist's desk next to the atrium opening in the floor. At that time the analysis procedure did not address the effect of the floor opening. The current analysis procedures now recognize the additional vibration that can occur next to openings in the floor.

Although in recent years, the structural engineering profession has made significant advancements in the analysis methods used to predict the extent of floor vibration that will occur in a structure, the application of these principles is still more of an art than an exact science. Everyone reacts to vibration differently. Vibrations that are imperceptible or barely perceptible to some people can be very objectionable to others, just as only some people get motion sickness during an airplane flight. According to John Ashbaugh, Steven Schaefer Associates' project manager for the SCPA building described in the previous article, "On that project, vibration control was a delicate balance between the effect the architect was trying to achieve, the amount of additional framing and mass that could be added, and the additional cost of the framing and mass."

In general, with the longer spans used in new office buildings, composite structural steel beams (beams constructed integrally with the concrete floor slab so that they share load and act as a single unit) are much better at producing a floor with acceptable vibration properties than typical floor framing with bar joists. Tom Lemmel, Vice President of Construction at Cincinnati United Contractors, Inc. (CUC), says that clients who want Class A office space definitely want a structure without objectionable vibration. In his experience, with typical bar joist floor framing and open office space, not only do occupants feel the floor move when someone walks by, but the floor continues to vibrate after the initial deflection. With composite beam framing, he says that the occupant may feel the initial deflection but there is no continuing vibration which is considerably less objectionable to most people.

On an office project Steven Schaefer Associates designed for CUC last year, we compared the cost of a composite beam floor vs. a bar joist floor, both designed to minimize vibrations. The weight of the steel floor framing was 13% less for the composite beam system. This system also could be erected faster and at a lower cost and was 7 ½ inches shallower than the joists. Thus, CUC decided to use composite steel framing. Typical composite framing was able to be used for most of the floor without having to increase the beam sizes to reduce vibration. The only areas where heavier beams were required on this project were adjacent to floor openings.

Not all projects where floor vibration is being controlled use composite structural steel beams. On a number of projects we have used the heavier and stronger LH series bar joists at two to three times the more typical 2- to 2 ½-foot spacing. To span the additional distance between joists a thicker concrete slab is used. This system becomes more economical if the building is large enough that the steel erector can assemble entire bays of joist framing on the ground and erect the entire bay in one lift rather than piece by piece. The economics of whether to use a joist system or composite beams frequently depends on the market conditions at the time. Thus, it is frequently necessary to prepare preliminary designs for both systems.

In summary, to economically control floor vibration requires cooperation and coordination of the owner who decides how much vibration is acceptable, a knowledgeable and experienced structural engineer who analyzes the structure using the correct parameters, and a contractor/construction manager who considers the cost and constructability of the different options. It is imperative that we are all involved in this process early to get started on the right track to produce a project that performs to the client's expectations at the most economical price.