NGI, NORWAY

Shake, Rattle, and Roll

Norwegian researchers are tracking how low-frequency sound waves travel within buildings so that they can recommend design adjustments to alleviate annoying vibrations.

by **JENNIFER HAND**

Anyone who has slept near an airport will know the sensation — an early morning flight wakes you from sleep, not only because the engine is noisy but also because everything around you seems to be shaking. Likewise, people living near wind turbines, military sites, or hospitals with helicopter landing pads often complain that windows rattle and everyday objects buzz when there is external noise. More puzzling for them is the fact that even when they can discern no sound, they may still notice irritating vibrations.

If the response of the sound is 20 vibrations per second (20 Hz) or less, it is described as infrasound, meaning that the original sound is not usually audible to the human ear. The effects, however, are very easy to detect. As waves hit windows, spread to the floor, and affect internal walls, they induce a noticeable indoor vibration. Low-frequency sound waves are notorious for their potential to create annoying disturbances.

⇨ LOW-FREQUENCY SOUND WAVES IN BUILDINGS

Noise is part of modern life and there are formal standards that use sound pressure level measurements to recognize high-frequency sound waves at levels of sensitivity, intrusion, and danger for humans. According to Finn Løvholt of the Norwegian Geotechnical Institute (NGI), the generation of building vibration due to infrasound is an area of research that has not been explored extensively. For this reason, NGI, an international center for research and consulting within the geosciences, has been running investigative programs for several years on behalf of the Norwegian Defence Estate Agency.

“Low-frequency sound encounters less absorption as it travels through the air than higher-frequency sound, so it persists for longer distances. The amount of sound transmitted from the outside to the inside of buildings is greater. We are interested in what happens at the threshold of hearing,” explains Løvholt. “We want to understand how sounds from external sources interact with buildings and generate vibration that is perceived by people. We can then recommend countermeasures to prevent vibration and may be able to propose standard units that recognize the need to account for the ‘annoyance’ factor.”

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⇨ SIMULATING THE SPREAD OF SOUND WAVES

Løvholt and his colleagues decided to create a computer model that would allow them to pick apart the mechanism of low-frequency sound waves hitting and penetrating a building. They used the COMSOL Multiphysics® software to simulate a wooden structure with two rooms separated by a wall (see Figure 1, top), closely mimicking the laboratory experiment setup. Within the model, they assigned a loudspeaker to one room, a microphone to the other, and placed various probes around the structure in order to monitor sound pressure levels and vibrations. Every component was

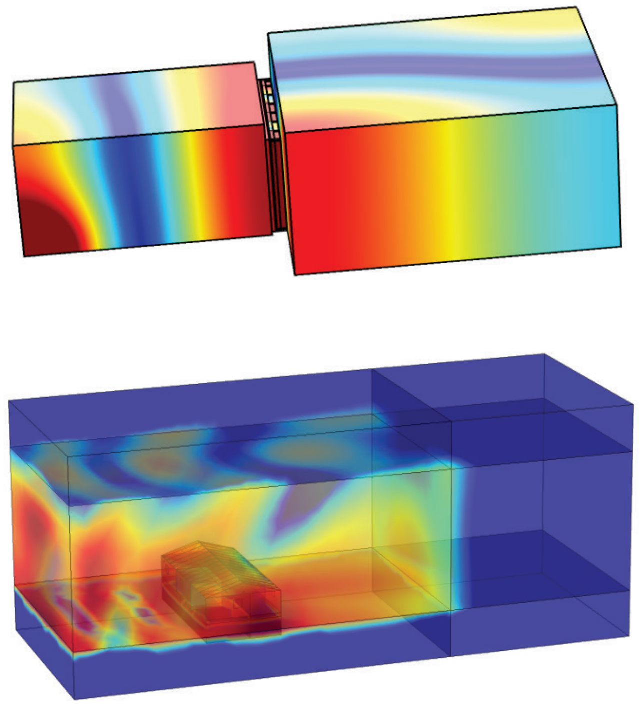

FIGURE 1. Top: Simulated sound pressure in a laboratory with two chambers divided by a wall. A loudspeaker is placed in the room on the left-hand side. The simulations show that the acoustic resonances within each room affect the sound insulation. Bottom: Simulated low-frequency sound originating from outside, around, and inside a building. In both cases, the colors indicate the variation in the sound pressure within the rooms and the wall cavities.

carefully modeled, including the steel frame, the air cavity and studs in the wall, the windows, the plywood sheet, and the plasterboard. "Each element has a resonance that depends on the wavelength of the sound wave and the pressure distribution. For example, there is high pressure in the speaker room and lower pressure in the microphone room, and the resonance of a wall will depend on its length, thickness, and stiffness," explains Løvholt.

The team also had to recognize compound resonances created when two components are joined, such as two pieces of timber that are screwed together. "The advantage of COMSOL Multiphysics is that it allows us to enter all the parameters we need to monitor. In particular, it enables us to couple physics, so we can, for example, look at the acoustics of open-air sound interacting with indoor structural dynamics. The coupling works both ways so we can identify feedback. This coupling is crucial for our analysis because sound waves can generate a huge range and variety of resonances. The model really allows us to see these."

The NGI team then verified their simulation with laboratory testing of low-frequency sounds as they were transmitted through a wooden construction with two rooms. Løvholt explains that the motion of the wall and the sound pressure level are the main quantities measured and results show very close correlation to the COMSOL Multiphysics model (see Figure 2). "The response of the real wall is very clear and the model mimics it almost perfectly. This is the most spectacular aspect."

The model shows that the transmission of sound within a building is governed by the way in which low-frequency waves interact with the fundamental modes of the building components, the dimensions of the room, and the way in which air leaks from the building envelope. Vibrations in ceilings and walls seem to be the dominant source of low-frequency indoor sound, with floor vibration driven by sound pressure inside the room.

CHEAPER AND QUICKER THAN PHYSICAL TESTING

"We now have a tool to predict sound and vibration at low frequencies," Løvholt says. "We can use it to design and test mitigation measures such as the lamination of windows and the stiffening of walls — if a wall or window moves less, sound transfers less. In addition, the model shows us the influence small details have on the system; for example, how the screw connection between studs and plasterboards can reduce the effect of a countermeasure, as they actually reduce the overall stiffness of the structure."

The next stage for the team is full-scale field tests on a real house in an area of Norway that is exposed to aircraft noise. Meanwhile, the team will continue to use and develop the model. "We have never achieved this level of agreement with real-life testing before and it is all down to how we were able to model the different structural elements in COMSOL Multiphysics," concludes Løvholt. "The model enables us to make decisions and assign countermeasures. This is much cheaper and quicker than physical testing. The model may then be expanded to simulate the sound propagation and vibration in an entire building" (see Figure 1, bottom). ❖

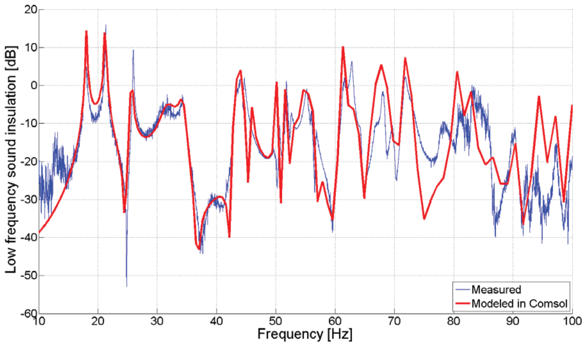

FIGURE 2. The model accurately captures the location of the resonances as well as the level within a few decibels. As the frequency increases, more modes in smaller and smaller structures will get excited. This shows as the increasing difference between the measurements and the model results.