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STIMULUS-RESPONSE MEASUREMENT OF FLOOR IMPACT SOUND

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ABSTRACT

A number of excitation techniques have been developed to evaluate impact sound transmission of light-frame floors. The ultimate goal of the excitation is to replicate the force and time duration of a human footfall so one can reliably rank the acoustical quality of the floor/ceiling system, especially at low frequencies where "booming" occurs. The most common excitation methods involve dropping an object of known mass from a known height so the kinetic energy delivered to the floor is consistent. The limitation of the energy method is that the force spectrum imparted to the floor can vary if either the dropped object or the floor finish has unknown (or unstable) characteristics. Variations in the force spectrum can contribute to inconsistent sound spectra in the space below. In order to control this parameter, research laboratories have occasionally used a transducer to calibrate impact forces delivered from dropped objects. This paper will discuss the concept of using a force sensor as the input signal for a two-channel impact sound measurement system *in the field.* A unique 13-kg force transducer platform was constructed to measure large dynamic forces at frequencies up to 100 hertz. An existing light-frame [wood] floor was used to explore this stimulus-response measurement technique. The force-versus-sound pressure data for this floor will be presented and compared to measurements involving conventional impact testing equipment.

1 - INTRODUCTION

In our consulting practice, we have experienced complaints from residents of multi-family housing who are dissatisfied by their floor's acoustical performance. This problem is especially germane to light-frame (or wood-frame) dwellings in which a "booming" sound is heard by those living below when people above walk on a carpeted floor. The traditional ISO tapping machine does not properly assess such "booming" sound for floors having soft coverings. The principal reason is that the 0.5-kilogram hammers of the tapping machine cannot impart sufficient mechanical energy below 100 hertz. In engineering parlance, the duration of the impulse from the 0.5-kilogram hammer is too short; hence, the force spectrum is inadequate at low frequencies where human footfalls generate "booming" sound (this is not to say that the ISO tapping machine is entirely without merit for use in exciting hard-surface floors; on a hard surface, the machine is capable of generating substantial sound power between 10 and 100 hertz due to a combination of 1) the large number of bending vibration modes within the floor, 2) five spaced hammers dropping in rapid succession, and 3) high impedance at the hammer-floor interface; when the lightweight hammers encounter a soft surface, however, the impedance relationship between the low-mass impactor and the compliant surface restricts the transmission of mechanical energy into the floor structure).

2 - BACKGROUND

Techniques for assessing the impact sound transmission of floor/ceilings has remained nearly unchanged since the development of the ISO tapping machine some 60 years ago. Japan has prepared a national standard for using a dropped tire as an impactor (JIS A 1418); however, the international community has yet to embrace the Japanese proposal, party because the equipment is not easy to transport (the Japanese apparatus involves a small automobile tire raised by a motorized linkage and then freely dropped onto the floor from a height of 0.9 meters; the motor, linkage and tire all constitute a heavy (and somewhat awkward) "bang" machine; the impulse imparted to the floor by the "bang" machine is shaped like a "half-sine", having a peak force of 4000 newtons and duration of 20 milliseconds). In the past few years, Tachibana and others have developed an alternative to the dropped tire. The alternative impactor is a 2.5-kilogram rubber ball consisting of a synthetic material having closely controlled hardness and damping properties. Both Japanese impactors are intended to supplement the traditional ISO tapping machine in the region below 100 hertz.

The dropped tires and balls have a common limitation − the force spectrum delivered to the floor depends on the terminal velocity of the dropped object as well as the material properties of the impactor and floor surface. Presumably, the velocity and the material properties of the impactor are well controlled, leaving only one uncertainty − the floor surface itself.

All dropped objects deliver an impact consisting of a force-time function (the integral of force and time is called an impulse). The duration of the pulse determines the shape of the force spectrum. If the duration of the force pulse changes from one floor surface to another, the shape of the force spectrum will vary. For example, if one uses an impactor on a floor with a hard surface and then uses the same impactor again after carpet is placed over the hard surface, the force pulse will be "stretched" in time (the peak force of the impact will be reduced in inverse proportion to its duration; hence, the value of the delivered impulse (i.e., in newton-seconds) remains constant). In spectral terms, the carpet causes the energy distribution within the force spectrum to shift from high to low frequencies.

The spectral shift in the force spectrum is a desirable characteristic if one wishes to rank floor surfaces for their impact insulation at high frequencies. A force spectrum dependent on the floor surface is *un*desirable, however, if the purpose of the test is to compare the dynamic properties among various floor structures. These dynamic characteristics include the driving point stiffness as well as the first few vibration modes; these cannot be quantified with precision unless one measures the force spectrum delivered to the floor structure itself (in our opinion, low frequency modes in the floor structure contribute to "booming" of light-frame floors).

During the past 10 years, our consulting group has performed field studies on floors having excessive "feelable" vibration at frequencies below 20 hertz. As part of this effort, a special platform was constructed so the force spectrum imparted to the floor could be measured.

Two types of force generators have been used with our platform. One is an electrodynamic inertial vibration exciter suitable for traditional measurements in structural dynamics. The other type is a transient force commonly referred to as a heeldrop (a heeldrop is generated by a person arching his or her feet upward about 60 millimeters and then free falling onto the floor; the impulse imparted to the floor by the heeldrop is also shaped like a "half-sine", having a peak force of 2500 newtons and a duration of 50 milliseconds (see Figure 2); relative to the "bang" machine, this longer duration shifts the principal components of the heeldrop force spectrum downward (see Figure 3)); see Figure 1, below.

The heeldrop has proven especially useful as a portable energy source for quantifying the structural properties of the floor up to 50 hertz. Its force spectrum is also ideal for investigating the "booming" sound in light-frame floor systems (the platform is often installed on top of a soft floor covering; thus, it is possible for the heeldrop force pulse to be "stretched" in time by the low stiffness of the floor surface; if such pulse "stretching" occurred, the energy in the force spectrum of the heeldrop would also shift downward; experience with both hard and soft floor surfaces has shown that this effect is small, probably because the compressed floor covering is relatively stiff under the static loads imposed by the body of the test person).

3 - MEASUREMENTS

Some examples of measurements obtained using the heeldrop are described in this section.

Figure 2 illustrates the force- time history of a typical heeldrop and Figure 3 is the resulting power spectrum:

3.1 - Floor dynamics

Figure 4 shows a plot of the ratio of heeldrop force to the floor's displacement. The driving point stiffness between two and ten hertz is 10^7 newtons per meter − remarkably good performance for a light frame floor spanning 6 meters.

Figure 5 illustrates the sound pressure from the heeldrop measured in the room below.

3.2 - Tapping machine

The same floor was also tested using an ISO tapping machine. Figure 6 illustrates the acoustical spectrum measured in the enclosed room beneath the floor.

Figure 1: Photograph of force platform with an individual about to perform a heeldrop; the two thick plates are mechanically connected at each corner only by force transducers; the core of each plate is fabricated from a metal honeycomb material to attain high stiffness and low mass; the small box visible between the plates has an output connector that serves as a summing junction for charge signals from all four matched force transducers; the two black discs on the upper plate are electrical switches used to trigger the measuring instruments at the instant the heels contact the platform surface.

4 - CLOSING REMARKS

- Low frequency vibration modes contribute to the "booming" sound experienced by people located beneath light-frame floors.
- The ISO tapping machine can excite these low-frequency modes only when a hard interface exists between the hammer and floor surface.
- Certain dropped objects (tires and rubber balls) are capable of exciting these vibration modes for any condition of floor surface. The force spectrum delivered to the floor structure will vary depending on the floor surface.
- The heeldrop is a practical force generator for exciting the floor's low frequency modes as well as quantifying its structural dynamics.
- Measuring the force input provides useful information about the floor's driving point stiffness and the characteristics of the first vibration modes.

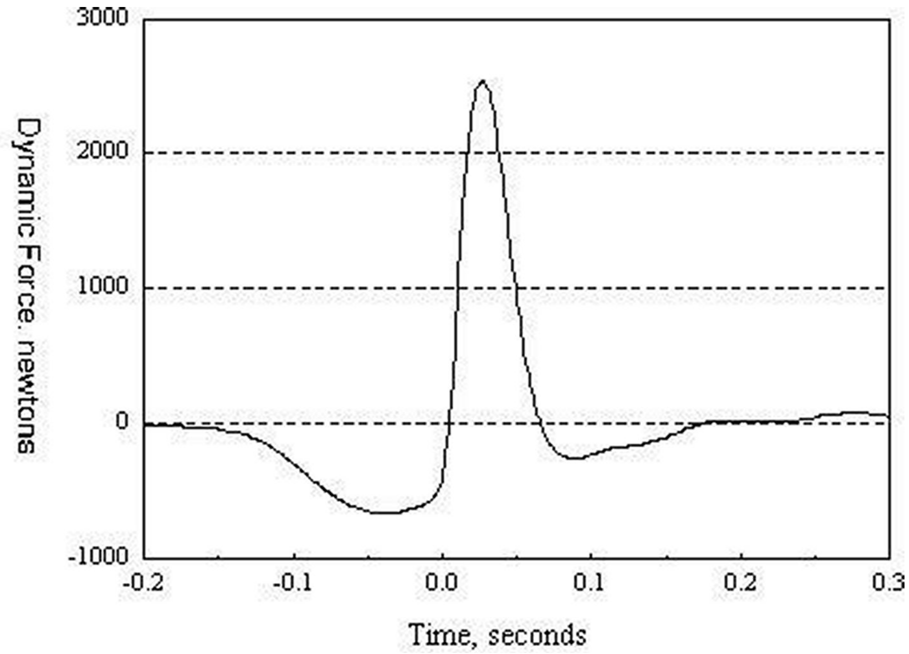

Figure 2: Time history of heeldrop over 0.5 seconds; the peak force of the "half-sine" force pulse is 2500 newtons and its duration is 50 milliseconds; the negative signal in the region preceding the heeldrop pulse is due to the human body in partial free fall (i.e., the force from Earth's gravity is temporarily reduced).

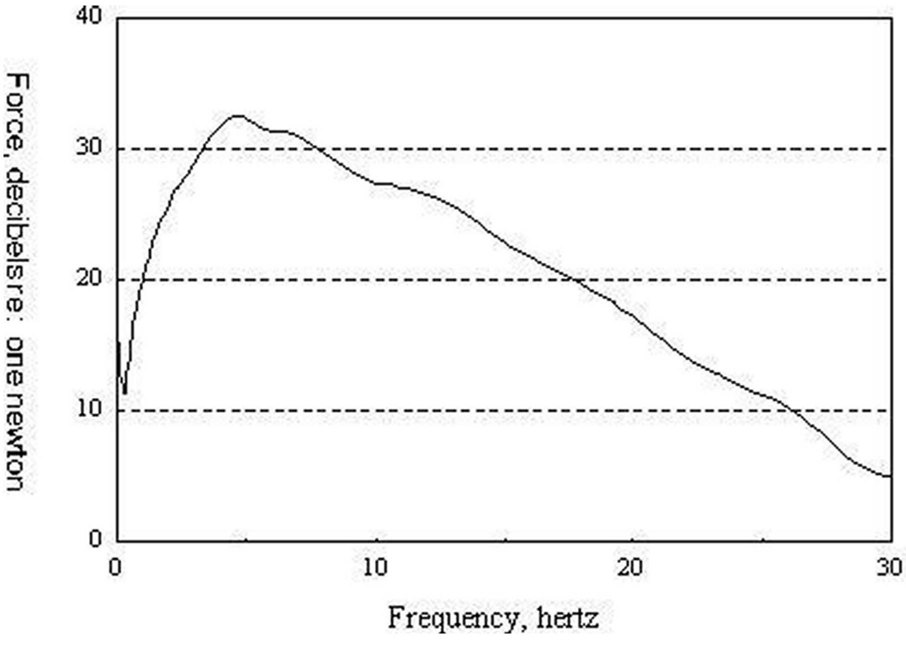

Figure 3: Power spectrum of heeldrop measured using a four-second FFT record; the amplitude decreases above and below the dominant peak at five hertz (note: the original 50-hertz span of the FFT has been truncated for clarity).

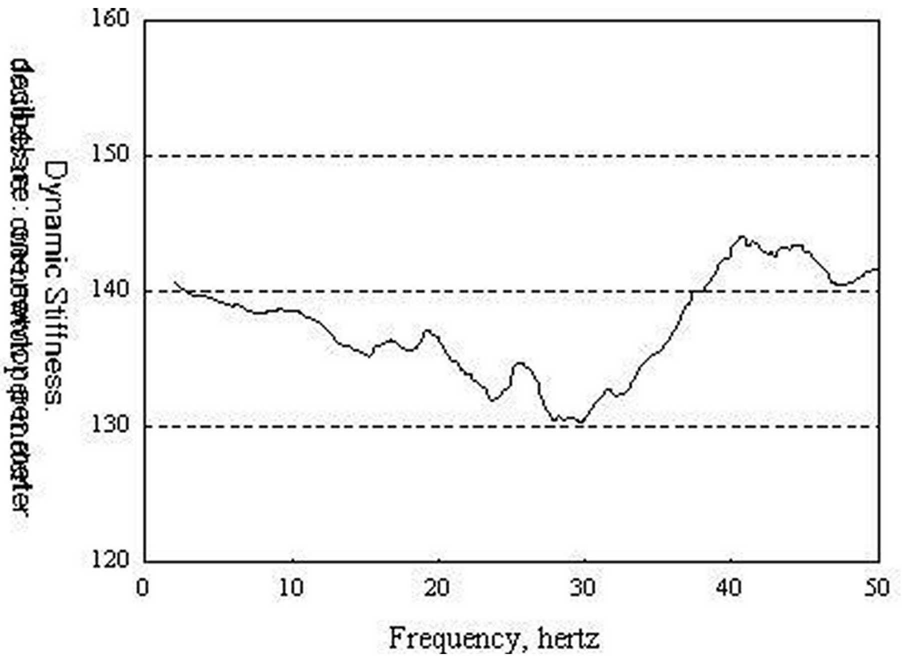

Figure 4: The frequency response function (”transfer function”) of force versus displacement for the test described in the text; the first mode of vibration for this floor appears as a ”dip” in the spectrum at 30 hertz.

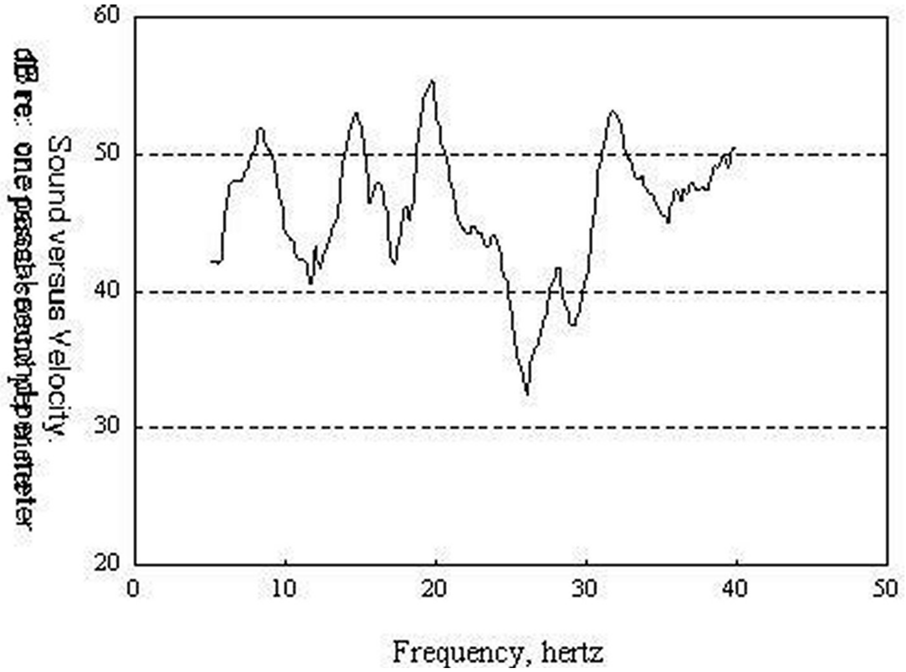

Figure 5: The frequency response function of sound versus vibration velocity; both the floor modes and the room acoustical modes are influencing this measurement; the data have been truncated to eliminate information having low coherence.

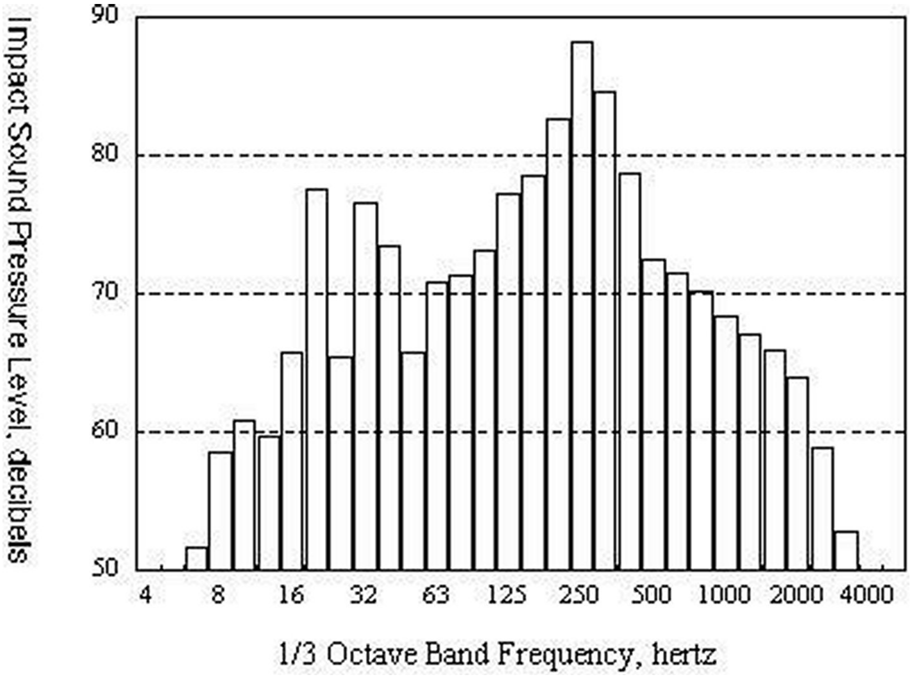

Figure 6: Sound spectrum of the same hard-surfaced floor tested with an ISO tapping machine; the [ASTM] IIC rating of 33 decibels is controlled by the 250 hertz band; the 20 and 31.5 hertz bands measured with the tapping machine have significant amplitudes similar to the acoustical response found during the heeldrop measurement (see Figure 5).