Transient vibration in light frame floors

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Transient Vibration in Light Frame Floors

Vibration passagère de planchers légers

Vorübergehende Schwingung leichter Unterzugsdecken

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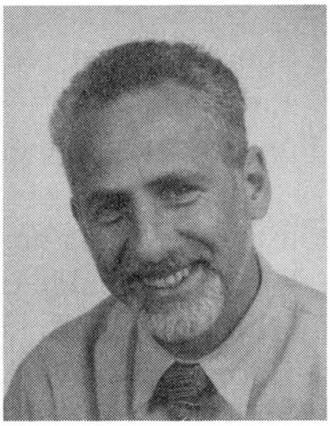

Anthony Nash is an acoustics/vibration consultant practicing in California. He has worked on noise and vibration projects for twenty years. His interest in floor vibration arises from his consulting experience with residential and commercial buildings where occupants have inquired about solutions to low frequency noise and vibration generated by footfalls.

SUMMARY

A number of long span wooden floors in existing buildings were evaluated with the so-called heeldrop test method to simulate vibration from a human footfall. The floor systems behaved differently than predicted from the dynamic model developed for heavy frame floors. The low bending stiffness of the thin floor diaphragm apparently supports a travelling wavefront that causes annoyance to people located far from the impact point.

RESUME

Plusieurs planchers en bois, de grande portée, dans des bâtiments existants, ont été étudiés à l'aide de la méthode d'essai «heeldrop». Utilisant cette méthode, on a simulé la vibration d'un pas humain. Les systèmes de planchers ont réagi différemment de ce que prévoyait le modèle dynamique réalisé pour des planchers de charpentes lourdes. La faible rigidité à la flexion du plancher mince semble permettre la diffusion d'une «onde» désagréable pour les gens situés loin du point d'impact.

ZUSAMMENFASSUNG

Eine Anzahl langbrettiger Holzdecken wurde in bestehenden Gebäuden mittels der sogenannten Fersenfall-Prüfmethode bewertet, um dabei die Schwingung infolge eines menschlichen Fussschrittes zu simulieren. Die Deckensysteme verhielten sich anders als man es von dem dynamischen Modell voraussagte, welches für schwere Decken entwickelt wurde. Die geringe Biegesteifigkeit der dünnen Deckenscheibe unterstützt offensichtlich eine sich ausbreitende Wellenfront, die für Leute, die sich weit vom Auftreffpunkt befinden, eine Störung verursacht.

INTRODUCTION

In the U.S.A., light frame wood floors are economically attractive for low-rise residential and commercial buildings. The floor framing system is usually solid lumber for clear spans up to 6 meters and open web trusses for spans above 12 meters. The framing typically supports a plywood floor diaphragm less than 30 mm thick. Although such floors can safely sustain a uniform load of 500 kg/m^2, the total service load is usually 1/10 of the design limit.

For purposes of discussing floor vibration, we shall divide floor systems into two categories — "short-span" and "long-span." Since short-span floors have been extensively treated in the literature, this paper will focus on long-span systems.

Long-span floors can be constructed using heavy or light framing. Both heavy and light frame long-span floors are capable of exhibiting annoying vibrations when excited by human footfalls. Research in this subject has concentrated on relatively massive concrete floors supported by heavy steel framing. This paper summarizes several field studies of transient vibration in light frame long-span floors.

BACKGROUND

Lenzen and others [1,2,3,4] conducted extensive laboratory and field investigations on heavy long-span floors in the 1960's and 1970's. Their efforts culminated in a quantifiable test method for rating the acceptability of floor systems where people sense the walking of others. Lenzen experimented with several techniques for simulating the effects of a human footfall. He concluded that all the significant parameters of annoyance could be derived from a test impact known as the heeldrop.* The heeldrop is analogous to the use of an instrumented hammer blow used in modal analyses of structures.

The three relevant floor parameters arising from the heeldrop are:

1) peak dynamic displacement
2) frequency of free vibration
3) damping

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* A heeldrop is generated by an 80 kg person arching his heels up 60 mm on the balls of his feet and then free-falling onto the floor. Figure 1 is a force-time history of a standard heeldrop. The peak force is about 2200 newtons and the duration of the impulse is 50 milliseconds. The force spectrum of the heeldrop transient is well matched to the modal frequency range of long-span floors.

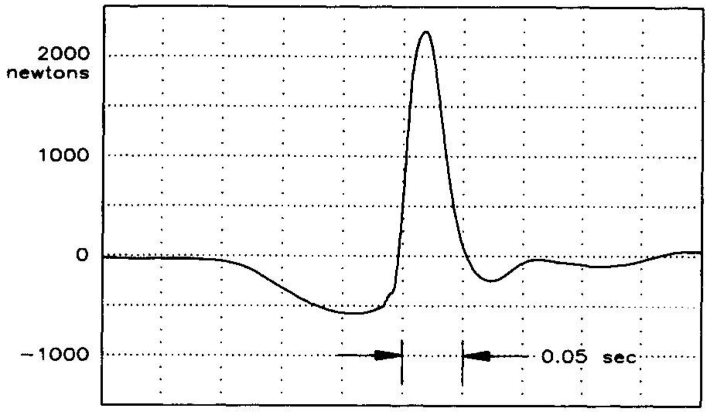

FIGURE 1: HEELDROP FORCE

Although the peak dynamic displacement is generally unaffected by the amount of damping, people are very sensitive to the duration of free vibration induced in the floor by a footfall. Long-span floors with low damping are particularly undesirable because human annoyance increases significantly with duration of the vibration transient.

Lenzen proceeded to develop a vibration annoyance scale based on the response from a standard heeldrop applied to a floor with moderate damping. Figure 2 is a chart illustrating four distinct regions of human perception for the heeldrop test. Each region is bounded by sloping lines that represent products of peak displacement multiplied by frequency (a "pseudo velocity"). In order that ordinary footfalls are sensed as "slightly perceptible," the heeldrop response should not exceed 1.25 [mm-hertz].

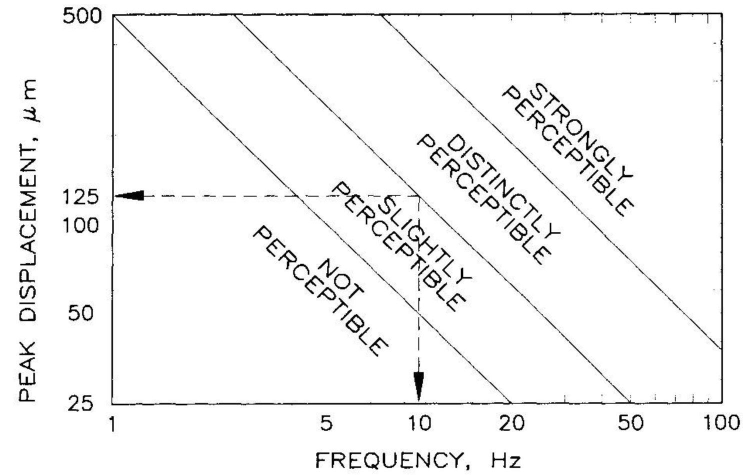

FIGURE 2: VIBRATION ANNOYANCE SCALE

The heeldrop method is useful for characterizing the global performance of a floor in terms of human annoyance. This method is analogous to firing a pistol in a large room to study sound propagation of music and speech. Impulsive excitation generally helps the engineer identify properties of a physical system such as transit speed, early reflections and decay rates. Since damping in multimodal dispersive structures is difficult to predict, the heeldrop test is a more accurate assessment of total system damping because the [viscous] human body absorbs mechanical energy whenever it is in contact with the floor.

The modal behavior of a light frame floor is sensitive to the mass contributed by the person conducting the heeldrop test, hence, the test subject affects the dynamic displacement and modal frequency distribution. In order to circumvent this problem, some researchers [5] prefer to measure the local stiffness of the floor statically or impact it with a lightweight device (e.g., a hammer).

FIELD STUDIES

In the past three years we have evaluated the characteristics of several light frame long-span wood floors. These studies were prompted by people complaining about floor vibration in certain types of buildings. The floors in these buildings were constructed with open web trusses spanning between 10 and 14 meters. Figure 3 is a photograph taken from the underside of a typical floor system. The open web trusses are seen receding into the plane of the paper. The photograph also illustrates some cross-bracing that had been installed in an earlier attempt to alleviate complaints by the occupants. Heeldrop measurements conducted on this floor placed it in the "strongly perceptible" region of the rating scheme.

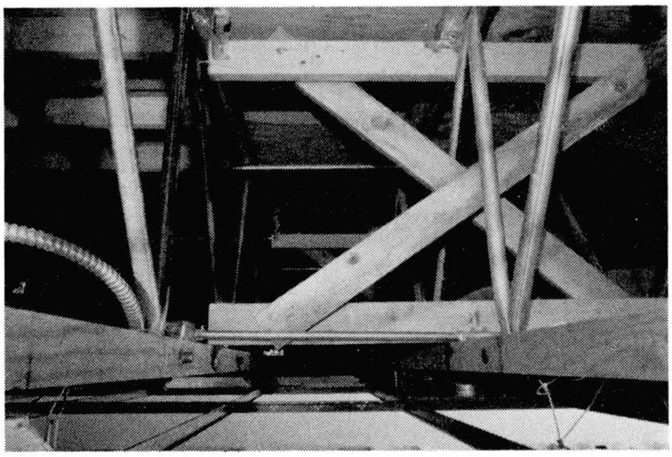

FIGURE 3: VIEW OF FLOOR FRAMING

Figure 4 is a typical [inverted] displacement-time history measured at the midspan of such a floor. The displacement transient is a rapidly decaying sinusoid having a peak amplitude of 1.1 mm and a free vibration frequency of 5.7 hertz. The product of peak amplitude and frequency is 6.3 [mm-hertz]. Several observers agreed that the response was indeed "strongly perceptible."

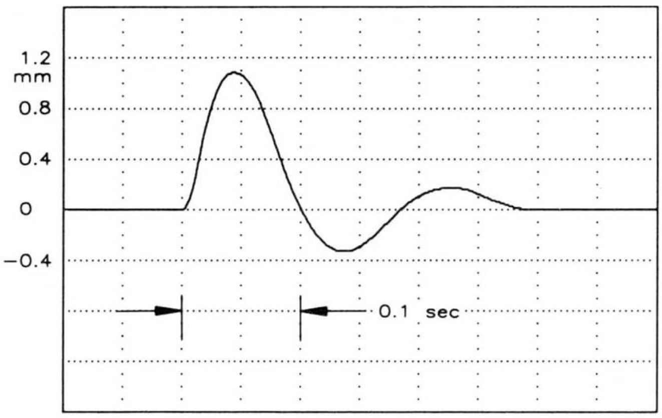

FIGURE 4: FLOOR DISPLACEMENT

DISCUSSION

During these tests, we observed that the transient response using the heeldrop method did not compare well with the floor's steady state response measured with a 45 kg inertial vibration exciter (the peak force of the exciter was 200 newtons). The frequency of the first transverse mode of vibration differed by 10 to 30 percent between the two test methods. To evaluate damping, the exciter was also driven with sinusoidal transients at a frequency centered on the first [steady-state] mode of vibration. The apparent damping measured with this technique depended on the local position of the exciter. Figure 5 is one example of a free vibration decay after the exciter was stopped. The decay over the first 30 decibels was so rapid that the response near the source was dominated by ringing of the electronic filter used to process the accelerometer signal. This characteristic suggested that either the floor system had extremely high damping or that the mechanical energy propagated away from the source.

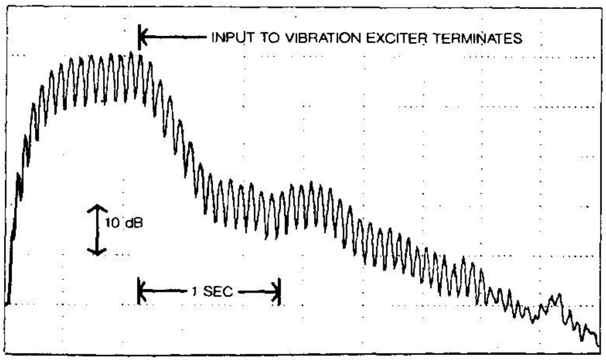

FIGURE 5: DECAY OF FLOOR VIBRATION (7.5 HZ)

Further tests using the heeldrop method tended to confirm the propagation hypothesis. Figure 6 illustrates the acceleration and displacement measured at a joist midspan 10 meters away from the impact point (which was also at a joist midspan). In this figure, the floor received a heeldrop impact at t = 0 and the response commenced t = 100 milliseconds later (propagation speed = 100 meters/second.) The reduction in peak floor displacement from the impact point to the distant measurement location was approximately 20 decibels.

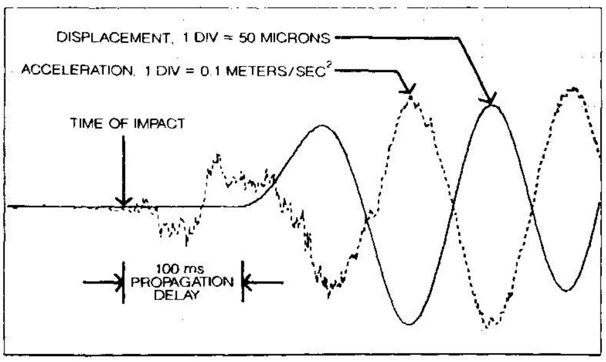

FIGURE 6: VIBRATION 10 METERS FROM HEELDROP

CONCLUSIONS

- When excited by impacts, a thin floor diaphragm with low bending stiffness behaves differently than predicted by the heavy steel frame model.

- Since adjacent joists are dynamically decoupled from the thin floor diaphragm, the relatively slow bending waves ripple outwards with high displacements, annoying people located both near and far from the impact point.

- Improving the vibration characteristics of light frame floors will require either significantly attenuating propagating wavefronts or increasing the bending stiffness of the floor diaphragm so its propagation speed is nearly infinite. An infinite propagation speed means that all joists will resist local impact forces at the same time in inverse proportion to their distance from the impact point.

We wish to acknowledge Trus-Joist MacMillan for their support during the field studies.

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