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TRANSIENT VIBRATION OF LIGHT FRAME FLOORS (PART IV)

A Nash

Charles M Salter Associates Inc, 130 Sutter Street, San Francisco, California, USA

INTRODUCTION

This paper is one of a series discussing feelable vibration caused by people walking on long span floors. Since 1990, we have performed a number of field measurements to help identify the reasons that the dynamic characteristics of certain light frame floors can annoy people, whether they are living or working in buildings.[1, 2, 3]

Our earlier field measurements used perceptual criteria developed by Lenzen [4] in the 1960s and later refined by Murray.[5] The criteria, in turn, were based on a single-degree-of freedom model involving an isolated beam/floor segment vibrating transversely (i.e., up and down). This model enabled the use of simple algebra to calculate the peak response of the floor when excited by a defined transient force such as a footfall. The Lenzen/Murray perception criteria and structural model were linked by a third element — a standard impulsive test method called a "heeldrop" that is still used for floor vibration analyses, both analytically and experimentally.*

* 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.

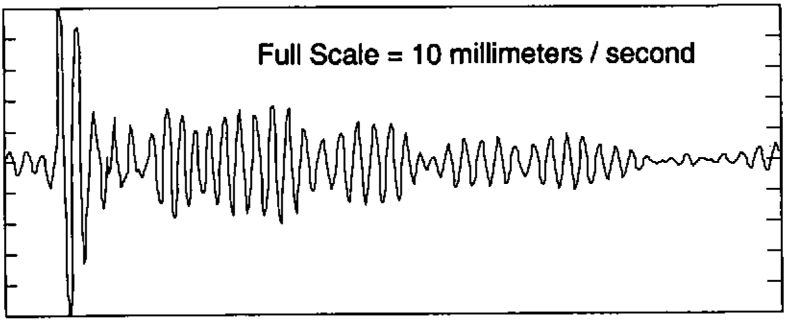
In the U.S.A., this triad of criteria, model, and test method is still being employed by structural engineers to assess the vibration susceptibility of heavy-frame floor designs. In our previous studies, we found that the single degree-of-freedom model is not accurate for light frame floors, especially those with spans exceeding six meters. This paper describes an ongoing field study of another long span floor which also fails to perform like the historical Lenzen/Murray construct. In this case, however, the floor system happened to be ***heavy frame***.

DISCUSSION

The particular floor forms a mezzanine for open-plan offices. It is supported by open-web steel joists spanning 11 meters and extends 34 meters in the direction perpendicular to the joists. The floor was constructed using lightweight concrete poured onto a corrugated steel floor deck. The concrete and deck have a surface mass of 160 kg/m^2 — a value three times that of typical light-frame wood floors. Initially, most of the floor area was free of partitions, ductwork and other accessories which commonly behave like vibration dampers. Prior to occupancy, the building owner visited the site and experienced annoying vibration resulting from a heavy person walking on the mezzanine. The owner asked the construction team to investigate.

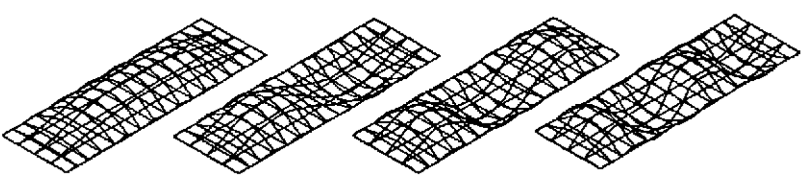
We worked with the structural engineer to conduct several floor vibration measurements using the traditional "heeldrop" test augmented by an electro-mechanical vibration exciter. The floor's response to the "heeldrop" impulse felt like a "bounce" followed by "aftershocks" — a phenomenon observed previously on other long span floors. Figure 1 illustrates eight seconds of floor vibration measured subsequent to a heeldrop. The alternating reinforcement and cancellation (or "beating") of amplitude in the decaying transient is probably the cause of the "aftershock" sensation. This "beating" implies that a number of panel modes having nearly the same frequency are interacting from moment to moment. Clearly, this floor is not behaving like a single degree-of-freedom system.

Figure 1: Floor Velocity After Heeldrop



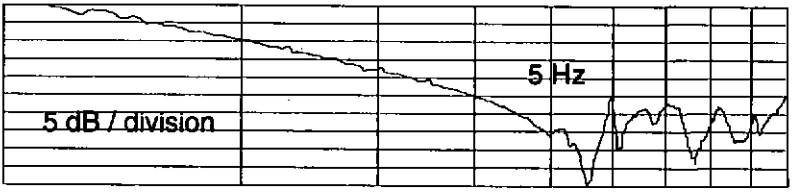
In order to understand the floor system's behavior better, the structural engineer created a mathematical model using a finite element program. Some of the resulting modal frequencies and "operational deflection shapes" of the floor diaphragm are shown in Figure 2. The first panel mode has a frequency of 5.0 Hz. Higher order modes have frequencies of 5.2, 5.4 and 5.8 Hz. If these modes "beat" against one another, the interference pattern would occur at a rate determined by their mutual difference frequencies (i.e., every three or four seconds).

Figure 2: Operational Deflection Shapes



In order to confirm the model experimentally, we used a vibration exciter to measure a frequency response function at a joist midspan (see Figure 3). The notch around 5.5 hertz is probably a composite of the first several modes predicted by the finite element model. Isolating these modes in the field will require considerable effort as they readily exchange mechanical energy (i.e., the modes are well-coupled).

Figure 3: Force vs Acceleration



CLOSING REMARKS

As this paper was being prepared, we learned that the building owner and his staff have occupied the mezzanine and presently perform their work in an open office with no complaints. Since the time of our field measurements, the only known structural changes to the floor system involved the installation of two light frame partitions beneath the joists at the far ends of the floor. Ventilation ductwork and light fixtures were also added to the underside of the floor, possibly improving the damping of panel modes. We plan to remeasure the floor response in the near future to help quantify the reason(s) for the change in human reaction.

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