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TRANSVERSE VIBRATION TECHNIQUE TO IDENTIFY DETERIORATED WOOD FLOOR SYSTEMS

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The Forest Products Laboratory, USDA Forest Service, has been developing nondestructive evaluation (NDE) techniques to identify degradation of wood in structures and the performance characteristics that remain in the structure. This work has focused on using dynamic testing techniques, particularly stress wave and ultrasonic transmission NDE techniques for both laboratory and field investigations.

Our initial efforts were aimed at using stress wave techniques to identify wood degradation. In a previous publication,[1] we reported on an inexpensive experimental technique that was developed to observe longitudinal stress wave behavior in small wood specimens. The technique utilized a mechanical impactor to induce a wave in the specimen. Wave propagation was observed by placing a piezo film sensor on the surface of the wood. Output of the sensor was recorded and displayed on a digital storage oscilloscope. This technique enabled us to examine fundamental wave propagation characteristics and the biological degradation of wood. Recently, we investigated the use of speed of sound transmission to locate degraded regions in wood materials.[2] The test setup we developed consisted of two 84-kHz rolling transducers coupled to an ultrasonic transmitting and receiving unit. A stress wave was introduced into a specimen in the transverse direction by the transmitting transducer. The wave was received by the opposing transducer after it traveled through the specimen. Stress wave transmission times were displayed by the unit and recorded on a personal computer. Elevated transmission times were indicative of deterioration. With this technique, we were able to locate sections of deterioration in wood materials.

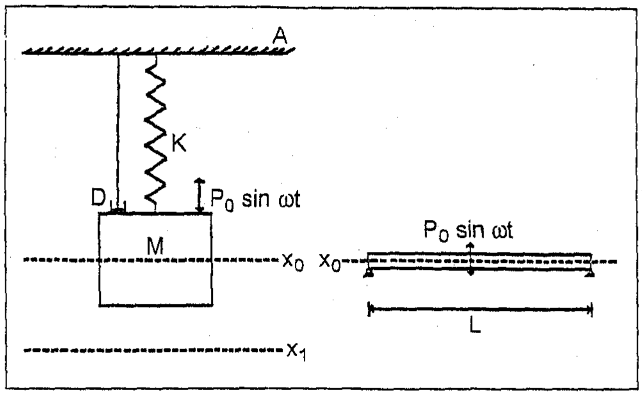

Fig. 1: Mass-spring dashpot vibration model (left) and transversely vibrating beam (right)

Currently, the use of stress wave techniques is limited to individual wood members. Evaluating each member of a structural system is labor intensive and time consuming. For in situ inspection of timber structures, a more efficient strategy would be to screen whole structural systems or subsystems in terms of their overall performance and serviceability. Examining the dynamic response of the structural system might provide an alternative way to gain insight into the ongoing performance of the system. Deterioration caused by any organisin reduces the strength and stiffness of the materials and thus could affect the dynamic behavior of the system. If, for example, one structural system or sections of the system were found to respond to dynamic loads in a manner significantly different from that of other similar systems or the surrounding sections of the system, a more extensive inspection of that system or section would be warranted.

Based on this conceptual strategy, we began to investigate the possibility of using transverse vibration techniques to inspect full-size wood floor systems by evaluating component systems. This paper describes the experimental setup developed for our research and typical results obtained from its use.

TRANSVERSE VIBRATION

Transverse vibration techniques have received considerable attention for NDT applications in the wood industry.[3] To illustrate these methods, an analogy can be drawn between the behavior of a vibrating beam and the vibration of a mass that is attached to a weightless spring and internal damping force (Fig. 1). In Figure 1, mass *M* is supported from a rigid body by a weightless spring whose stiffness is denoted by *K*. Internal friction or damping is represented by the dashpot *D*. A forcing function equaling P_0 sin wt or zero is applied for forced or free vibration, respectively. When *M* is set into vibration, its equation of motion can be expressed by the following:

$$M\left(\frac{d^2x}{dt^2}\right) + D\left(\frac{dx}{dt}\right) + Kx = P_0 \sin \omega t \qquad (1)$$

Equation (1) can be solved for either *K* or *D*. A solution for *K* will lead to an expression for modulus of elasticity (*E*) for a beam simply supported at its ends:

$$E = \frac{f^2WL^3}{2.46Ig} \qquad (2)$$

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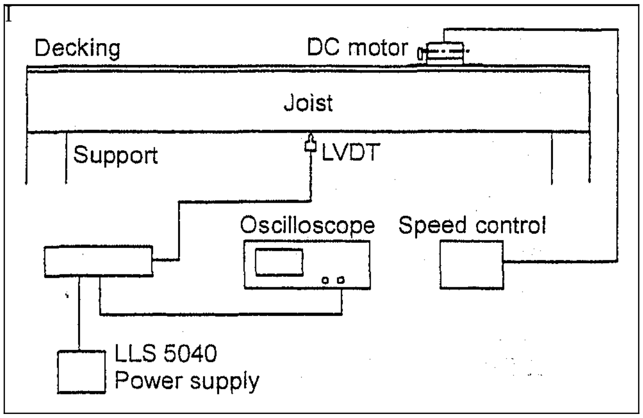
where

E = dynamic modulus of elasticity (Pa),
f = natural frequency (Hz),
W = beam weight (kg),
L = beam span (m),
I = beam moment of inertia (m^4), and
g = acceleration due to gravity (9.8 m/s^2).

Wood floor systems are typically constructed of wood joists, cross bridging, and decking. The stiffness of the joists predominates over the transverse floor sheathing. Thus, we can assume that a floor system behaves predominately like a beam with resisting moments in one direction only.

EXPERIMENTALSETUP

A schematic diagram of the experimental setup is shown in Fig. 2. The floor system was subjected to forced vibration imposed by a motor with an eccentric rotating mass attached to the floor decking (Fig. 3). The motor speed could be continuously changed to a maximum of 1800 rpm. The rotating mass weighed 251 g with an eccentricity of 30 mm. The response of the floor system to vibration was measured at the bottom of the center joist using a linear variable differential transducer (LVDT). Output from the LVDT was observed with a Nicolet Model 310 Digital Storage Oscilloscope. Using this setup, the damped natural frequency was observed by increasing motor speed until maximum deflection was observed. Damped natural frequency was then determined from the time–deflection data displayed by the oscilloscope.



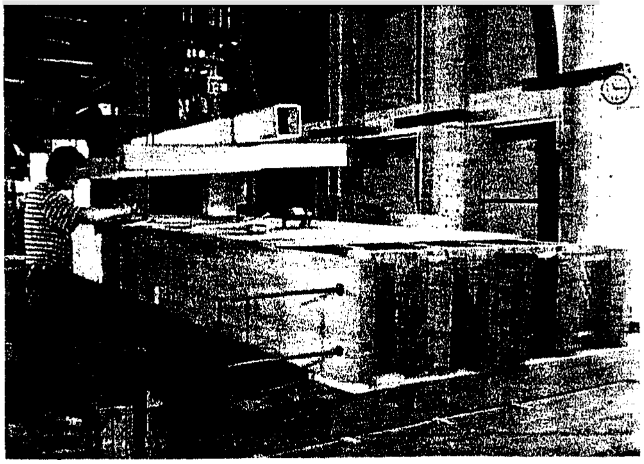


Fig. 3: Forced vibration was imposed by a motor with an eccentric rotating mass attached to the floor decking

Static bending tests were then conducted on the floor system to obtain load–deflection data by adding several hundred kilograms of static load at midspan of the joists and distributed over the width of the floor system. The stiffness (EI) of the floor was calculated by

$$EI = \frac{PL^3}{48\Delta} \tag{3}$$

where

P = static load (N),
D = deflection (m), and
L = floor span (m).

To examine the effectiveness and sensitivity of this experimental setup, we first used it to test three wood floor sections built at the Forest Products Laboratory. Each “lab-floor” section was constructed of five 50.8- by 406.4-mm Southern Pine joists spaced 30 cm on center, with a span of 5.94 m. Two floors were constructed from new materials; the third floor was constructed from material salvaged from a demolished warehouse.

The experimental setup was then used to evaluate floor systems in an old multi-bay building in West Lafayette, Indiana. The floors of 7 bays were examined. The floor systems were tested for both natural frequency and stiffness. We compared the measured damped natural frequency with the corresponding stiffness of the floor system.

RESULTS

The location of the forcing function (motor) and LVDT measuring device is a practical concern in floor system inspection. We first examined the sensitivity of results when-the motor and LVDT were at varoous locations in the lab-floor section. The LVDT was located at quarter and midspan on both the center and edge joists. The motor was located at quarter and midspan of the center joists. We found that the location of the motor and LVDT did not significantly affect frequency. The measured frequencies were generally within 0.1 Hz of the average value within the experimental accuracy of measurement. This indicated that any location of either LVDT or motor was acceptable provided we could get a strong response signal.

Table 1 shows measured frequency and stiffness for both new and salvaged lab-floor sections. The measured frequency values are damped natural frequency due to a rotating mass type excitation. Note that the salvaged floor section yielded a lower frequency (14.8 Hz) than did the new floor sections (16.2 and 16.3 Hz). The lower frequency of the salvaged floor was due to its decreased stiffness (measured as 13.2×10^6 Nm^2), compared to the stiffness of the new floor sections (14.9×10^6 Nm^2). This indicated that the effect of deterioration in the salvaged floor was detectable by a decrease in frequency when compared to the frequency of the new floor sections.

Table I –Results of Tests of New and Salvaged Lab-floor Sections

FLOOR SECTION	MEASURED NATURAL FREQUENCY f (Hz)	FLOOR STIFFNESS EI (10^6 Nm^2)
New floor I	16.2	14.94
New floor II	16.3	14.85
Salvaged floor	14.8	13.16

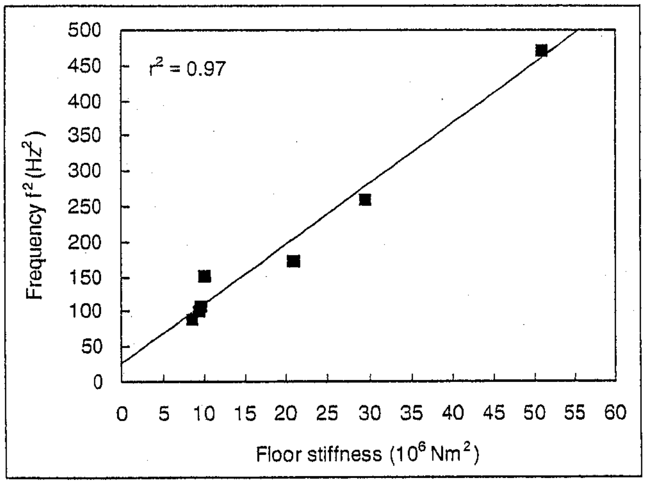


Fig. 4: Relationship between measured natural frequency and floor stiffness

Figure 4 shows the relationship between stiffness and measured natural frequency of the in-service floor systems in the West Lafayette building. The fundamental natural frequency of a structural system is dependent on the stiffness, mass, span, and boundary conditions of the system. For a continuous system that is modeled using a pin support on each end, the relationship between stiffness and natural frequency can be expressed as

$$EI = \frac{f^2 W L^3}{2.46g} \qquad (4)$$

where EI is the stiffness of the system. Given the weight and the span of floor systems, the stiffness of a floor is proportional to the square of fundamental natural frequency of the floor system. This relationship was shown to exist in the in-service floor systems (Fig. 4). Results of a linear regression analysis yielded a coefficient of determination (r^2) of 0.97. The stiffness of the in-service floor systems ranged from 8.53 to 50.87 × 10^6 Nm^2, The corresponding natural frequency measured in these floors ranged from 9.4 to 21.7 Hz. Based on testing results, three floor systems (f = 10.4, 10, and 9.4 Hz) were identified as severely deteriorated and unserviceable, one floor system (f = 12.3 Hz) was questionable and requires further inspection, and three floors (f = 13.2, 16.1, and 21.7 Hz) were identified as being in good condition.

CONCLUSION

The preliminary data presented in this paper show that the effects of deterioration in wood floor systems can be detected by measuring damped natural frequency. The forced vibration technique utilized in this research holds promise as an inspection tool. Further research is necessary to determine whether similar results can be obtained for floor systems with different floor spans and joist sizes and having various levels of deterioration.

References

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