DESIGNING TO REDUCE FLOOR VIBRATIONS IN WOOD FLOORS

by

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Acknowledgement

This paper is a summary of work done jointly between the department of Wood Science and Forest Products, Civil Engineering, and Biological Systems Engineering at Virginia Polytechnic Institute and State University. The collaborators include, Dr. Thomas M. Murray, Dr. Frank E. Woeste, Mr. Jamie Johnson, Mr. David Runte, and Mr. Bruce Shue. The work was sponsored by the United States Competitive Grants Program, the Wood Truss Council of America, and Trusjoist-MacMillan.

Introduction

Historically, wood floor systems were designed to conform to a deflection criteria that was meant to prevent plaster ceilings from cracking and were based primarily on “rules-of-thumb” and acceptable experience with static loads. Due to the relatively short spans used in wood buildings, vibration was rarely considered and caused few annoyance problems. Architectural changes imposed in recent years has resulted in a desire for larger rooms and consequently longer spans for floors.

Engineered products such as metal-plate connected trusses, I-joists, and laminated veneer lumber were developed to facilitate this architectural move to large open areas and longer spans. From a safety point of view, these products have performed exceedingly well and have been a cost effective alternative to other material substitutions. These products also resulted in increasingly light-weight floor systems and a significant reduction in the amount of wood material required to construct the typical building.

However, the traditional deflection criteria resulted in total deflections of long span floors that caused occupant annoyance, and owners began to complain about the vibration performance of wood floors. In other words, the requirements of design codes provide a safe structure, but fail to provide a serviceable structure.

Several researchers investigated the vibrational response of wood floors; including Polensek (1996, 1987), Chui (1988), Ohlsson (1988a-b), Onysko (1988), and Smith and Chui (1988). Most of these investigations resulted in design criteria intended to avoid floors being constructed with unacceptable vibration response. Combinations of fundamental frequency of the floor system, root mean square acceleration and deflection under concentrated loads at the center of the floor were used in the various proposals. However, many proposed criteria required information not readily available to designers, and are therefore of limited use. The results of the vibration analysis are then compared to acceptable values for acceptance or rejection of the design. If details of these criteria are of interest, the reader is referred to the individual publications for detailed descriptions.

A new criteria is presented in this paper that is based on work conducted by Runte(1993) and Johnson (1994). The work included both laboratory and in-situ investigations of wood floors, and a conscious effort to eliminate all unacceptable and marginally acceptable floor systems at the expense a few acceptable floor systems was made. The criteria uses mechanical properties published in general technical publications or design specifications that are readily available to the average architect, engineer, or contractor. The reader should be aware that this criteria should be considered as preliminary since the in-situ floors were under construction and occupancy loads were not included. A study is currently underway to retest the in-situ floors after the buildings have been occupied to verify the applicability of the criteria all wood floors.

Background of Criteria

In developing this design criteria, results of over 200 vibration tests of laboratory floor specimens and 89 vibration tests of floors in buildings under construction were used. Three types of construction were included in the tests: traditional lumber, I-joists, and metal-plate connected wood trusses. The floors were subjected to an impulse load of a man dropping from his tip-toes to his heels, and the acceleration and velocity time history were recorded for quantitative measurement of the vibration response. In addition, subjective ratings were assigned to each floor as to whether the floor had acceptable, marginal, or unacceptable performance when a second person walked nearby.

The criteria requires that the fundamental frequency of the joists and supporting girders be calculated using the equation:

$$f = 1.57\sqrt{\frac{386\ EI}{WL^3}} \tag{1}$$

where f is the fundamental frequency of the joist or girder in Hz, E is the modulus of elasticity in psi, I is the moment of inertia in inches’, w is the total supported permanent load, and L is the joist or girder span in inches. The fundamental frequency of the joists is effected by the vibration of their supports, and therefore, the frequency of the joists and any girder used to support the joists must be combined using the equation,

$$f = \sqrt{\frac{f^2_{joist} * f^2_{girder}}{f^2_{joist} + f^2_{girder}}} \tag{2}$$

The criteria requires that the fundamental frequency of either the individual joists and girder, and their combined fundamental frequency be greater than 15 Hz for the floor to be judged to be acceptable.

Effect of Criteria on Floor Design

The effect of this criteria can be seen in Figure 1 which shows the results of the 86 in-situ floor tests and how they relate to the acceptance criteria. As shown in Figure 1, none of the unacceptable or marginal floors would have been allowed under the proposed criteria. However, 16 floors that were judged to be acceptable would also not be allowed by the criteria. The cost of upgrading the floors falling below the acceptance criteria should be minimal. The upgrade may require increasing the depth of the truss or I-joist, or increasing the chord or flange size slightly in order to increase the stiffness of the joist. If girders are used to support one or both ends of the joist, they may have to be increased in stiffness to raise the fundamental frequency of the floor system to an acceptable level.

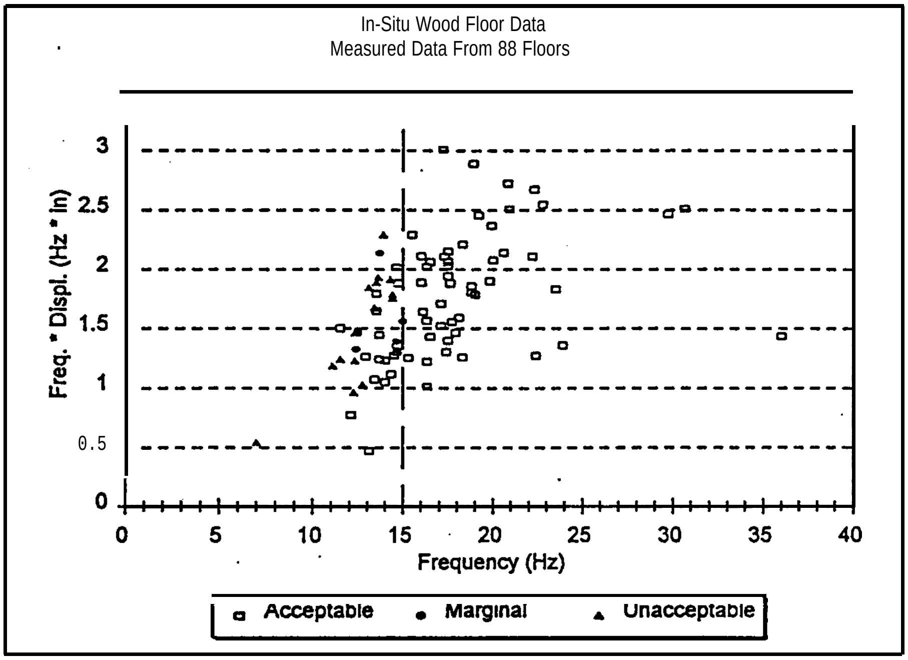

Figure 1: Measured frequency * maximum displacement versus frequency for in-situ floors. (Johnson, 1994)

If one considers the effect on allowable span for a metal-plate connected truss, the criteria will decrease the allowable span for long span systems. Figure 2 shows the allowable spans based on the proposed criteria for parallel chord trusses with chord modulus of elasticities of 1.6 and 1.9 million psi. The effect of the criteria is shown by plotting the maximum span to depth ratio versus allowable span. Notice that the maximum span to depth ratio is reduced by 50 percent when the span increases from 10 to 30 feet.

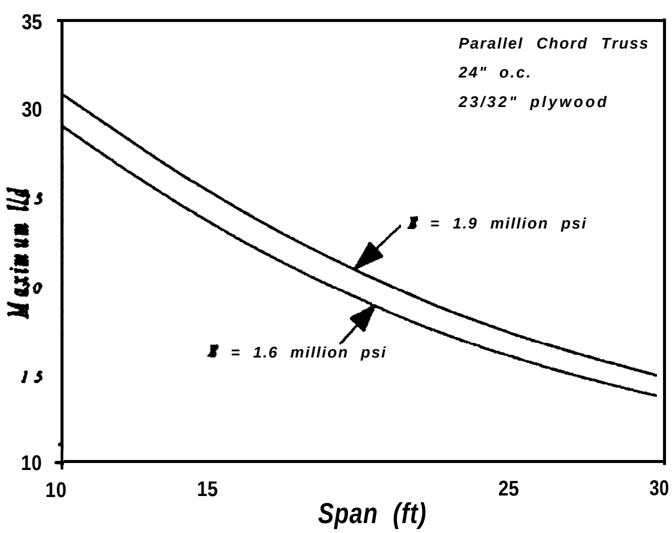

Figure 2. Effect of criteria on allowable span/depth ratio for parallel chord trusses. (Woeste, 1994)

greater than about 22 feet the traditional criteria is sufficient and the vibration criteria only needs to be used for spans greater than 22 feet for the specific conditions cited.

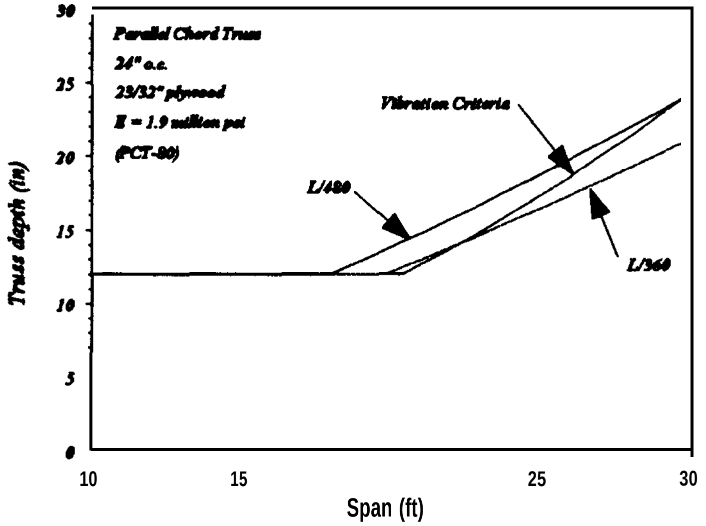

Figure 2: Comparison of vibration criteria with traditional deflection criteria. (Woeste, 1994)

Conclusion

A new design criteria for preventing annoying vibration in wood floor construction has been presented. The criteria requires that the fundamental frequency of the floor joists and combinations of joists and supporting girders be greater than 15 Hz. The criteria was developed using vibration test results of both Minatory and in-situ floors, is relatively easy to apply, and uses information that is readily available to the average architect, engineer, or contractor. The reader is cautioned that the design criteria is to be considered prelimay due to the effect of occupancy loads has been neglected. **A** study of the effect of occupancy loads is currently underway to verify the design criteria's effectiveness under typical load conditions.

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