Use of vibration techniques to determine the rotational stiffness of timber joints

Paul Crovella[1], Dr. George Kyanka[2]

Abstract A method for determining the rotational stiffness of timber joints using the natural frequency of vibration of the beam is presented. Reviewed research shows that joint stiffness is important for frame behavior when the relative value of joint stiffness exceeds the beam flexural stiffness ($\alpha > 1$). Lab results show that vibration could predict joint stiffness of both hardwood (within 17%) and softwood (within 16%) beams when restrained in a metal fixture ($\alpha > 1$). A beam tested in a metal fixture with sequentially weakened joints shows that the stiffness decreased with a matching decrease in frequency. Two softwood frames with all timber joinery, one with tight and one with loose joints, were tested. Results show that tight wood joinery can produce values of $\alpha > 1$. The stiffness values based on vibration ranged from 2-31% of the measured values ($\alpha > 1$). Finally, a discussion of the considerations for field application of the method is included.

Keywords timber joints, non-destructive testing, rotational stiffness, vibration

1. INTRODUCTION

1.1. Overview

To be able to structurally model an existing timber frame, the member properties (strength, stiffness, and dimensions) of the elements must be known, as well as the boundary conditions (strength and stiffness of joints) for each member. While extensive research has been performed to non-destructively evaluate the member material properties, in-situ determination of the member joint properties has not been widely investigated. In identifying critical research needs for the ASCE SEI, Ron Anthony wrote “Under design loads, seldom do wood members fail in a structure unless they are severely deteriorated. Failures generally occur at connections. Yet we have a wealth of knowledge about wood properties, but not the behavior of connections. Unfortunately, connections are critical in structure performance,…,and yet we do not have a reliable means to assess their condition or capacity.” (Anthony, 2008)

1.2. Theory

The fundamental frequency for a uniform beam is governed by the beam’s material properties and the joint stiffness (Eq. 1).

---

[1] Paul Crovella, Department of Sustainable Construction Management and Engineering, State University of New York – College of Environmental Science and Forestry, US, plcrovella@esf.edu

[2] Dr. George Kyanka, Department of Sustainable Construction Management and Engineering, State University of New York – College of Environmental Science and Forestry, US, ghkyanka@esf.edu

$$f_n = \frac{K_n (EI/w)^{1/2}}{2\pi l^2} \quad (1)$$

where f_n = Natural frequency of mode n (cycles per second), K_n= Constant dependent on the boundary conditions and mode, w= uniform mass per unit length (including beam mass), E = modulus of elasticity, I = second moment of area, l= length of beam

The value of K_n is not the value of the rotational stiffness of the joint, but rather a value that can be correlated to the rotational stiffness of the joint. An important point arises here: When considering a beam with semi-rigid joints, whether the joint stiffness is significant in the analysis or not, will depend on the ratio of the joint stiffness to the bending stiffness of the beam. When the joint stiffness is between 1 and 100 times that of the flexural stiffness, a change in joint stiffness produces a relatively large change in frequency.

2. METHODOLOGY

2.1. Experimental Apparatus

The frequency was determined using an accelerometer placed on the beam to produce an electrical signal due to the free vibration of the member

2.2. Beam Testing

A number of beams were tested to validate the approach

2.3. Frame Testing

Next, two timber "H" frames were fabricated with *Pinus strobus* to test the effect of creating joint stiffness using only timber joinery. One of these frames was fabricated with tight mortise and matching tenons and the other with loose.

Table 2 – Joint Stiffness (in-lb/rad) for "H" Frames w/% error

Boundary Conditions	Loose Frame Deflection	Loose Frame Equivalent Vibration	Tight Frame Deflection	Tight Frame Equivalent Vibration
Simply supported	0	-255,000 *	0	-66,000*
1 pin installed	-450	42,000 *	1,900,000	1,320,000 (-31%)
2 pins installed	180,000	282,000 *	2,290,000	2,360,000 (+3%)
2 pins w/load on column	No data taken	311,000 *	2,580,000	2,620,000 (+2%)

* $\alpha < 1$ no % error given

3. CONCLUSIONS

The understanding of the effect of joint stiffness on beam behavior is based on the relative stiffness of the joint and beam. The vibration method does not effectively distinguish low joint stiffnesses ($\alpha < 1$), but by determining the stiffness to be low, allows the designer to use an appropriate model (pinned joints). In the case of semi-rigid behavior ($\alpha > 1$), the method predicted the stiffness within 12%, on average. Since the stiffness can vary be an order of magnitude in this range, this 12% error can be considered in that context.