Lateral Buckling of Wood Composite I-Joists as a Mechanism Causing Falls from Elevation

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Wood composite I-joists are common materials used for floor and roof joists in residential construction. The shape of I-joists reduces the amount of wood fiber required to carry vertically applied loads. However, these joists have low stiffness in the lateral and torsional directions, requiring bracing by sheathing and additional bridging elements. During construction, workers may walk on these I-joists and induce lateral buckling, which could lead to worker falls. Walking loads contain both vertical and horizontal loading components which could induce lateral buckling. The purpose of this paper was to explore the loading and deflection of workers walking on unbraced I-joists to see if lateral buckling was initiated. A safety platform allowed workers to walk on unbraced I-joists safely. Measurements of the horizontal load and deflection of the top flange at mid span showed increasing load and deflection due to increased worker static weight, respectively. Differences in the load and deflection were observed between I-joists of different lengths and manufacturers. The phenomenon of lateral buckling may be more serious for overweight workers since the addition of horizontal load decreases the vertical load needed for buckling, and increased deflection may increase the tendency of workers to fall from unbraced joists.

Introduction

Wood composite I-joists represent a sizeable portion of new residential construction floor systems. I-joists are created from solid sawn, structural composite lumber (SCL) flanges connected with an oriented strand board(OSB) web [Hindman et al. 2005a]. As the complexity of residential housing increases, wood I-joists are used in longer spans, and as continuous and cantilevered beams [Hindman et al. 2005b]. The shape of I-joists tends to produce high bending stiffness in the vertical direction, but low bending stiffness in the lateral direction, and low torsional rigidity. These stiffness properties make I-joists vulnerable to lateral buckling, an instability condition where the joist deflects laterally and twists due to vertical loads. Previous research by Hindman et al. [2005b] and Zhu et al. [2005] studied the effects of static structural loads on I-joists. However, no research has been conducted pertaining to the lateral buckling of unbraced I-joists under construction loads. This condition is commonly seen in residential construction before the sheathing is attached to the joists. Falls are the leading source of injuries and fatalities in the construction industry, accounting for nearly one third of fatalities. Furthermore, fall accidents have been steadily rising over the past several years [Huang and Hinze 2003]. Since 1997, approximately half of all fall accidents have occurred on commercial and single family or duplex construction sites. The average fall height is approximately 11 meters, corresponding to structures of three stories or less. Almost half of fall accidents occur on job sites with a value of less than$250,000 [Huang and Hinze 2003]. These facts indicate that the majority of fall accidents may be occurring on residential construction sites. The motion of walking can be characterized by an ascending and descending movement of the effective mass of the human body as well as lateral propulsion. This motion is periodic with respect to the step frequency. Harmonic loads develop due to the loading of one foot and the simultaneous unloading of the other foot. An increase in the

dynamic load is observed due to the impact of the heel. This dynamic load usually results in a vertical load higher than the static weight of an individual. Huang et al. [2006] developed a mathematical model that defines these forces normalized by static weight to describe the force components of a single step.

Materials and Methods

The purpose of this research was to measure the loads and deflections of the I-joist when subjected to walking forces by workers traveling parallel to the length of the I-joist. A safety platform was constructed to allow workers to traverse the unbraced I-joist while being supported by a safety harness and lanyard continuously. Three different sizes of I-joist were used in testing from two different manufacturers. Joist 1 (J1) was 30.2 cm high and 610 cm long. Joist 2 (J2) was 35.6 cm high and 610 cm long. Joist 3 (J3) was from a different manufacturer and measured 30.2 cm high and 731.5 cm long. All materials were conditioned in the Wood Engineering Laboratory at equilibrium moisture content (EMC) of approximately 10%. Three samples of each joist were used for testing based upon the variance of previous measurements. Figure 1a shows the schematic of the safety platform. The platform was designed to accommodate the unbraced I-joist and provide a continuous lanyard connection to workers traversing the joist. The platform is approximately 610 cm long. Figure 1a shows the sides of the platform, which act as safety rails if the participants feel they are beginning to fall. These safety rails are located approximately 150 cm apart. The overhead beam is located directly above the unbraced I-joist. The trolley is clipped onto the bottom flange of the overhead beam and is able to move along the

length of the platform on steel rollers. A 152 cm self retracting lifeline is connected to the safety trolley. Participants attached the lifeline to their harness. Preliminary testing of the system was conducted to ensure that the retracting lifeline activated before a participant struck the floor. Figure 1b shows a participant walking on the joist.

Test subjects included male construction workers and students weighing from 60.3kg to 128.3 kg. All data collected from test subjects conformed to the Virginia Tech Internal Review Board guidelines. Test subjects were asked to traverse the beam at their own pace. Each participant traversed the beam two times (forward and back). The participants were instructed to use the safety rails only when necessary to prevent a fall. Two different end supports were constructed to hold the ends of the I-joist. Vishay BHL U3SB-A "S" type load cells with a 22.2 kN capacity and an error of less than 1 percent were be placed at each end of the beam to record the vertical reaction. These two load cells could be used to establish the relative position of the participant along the joist. At one of the supports, two load cells were also attached in horizontal directions at the top and bottom flanges. The horizontal load cells measured the lateral force exerted on the joist, as well as any torsional resistance at the supports. The end reactions combined with the I-joist flange reactions were compiled to produce the combination of loads that each participant applied to the I-joist through walking. A pair of 50.8 cm string potentiometers were placed at the mid-span and quarter-span locations along the joist.

At each location, one potentiometer was attached to the top flange and another was attached to the bottom flange. The change in deflection of
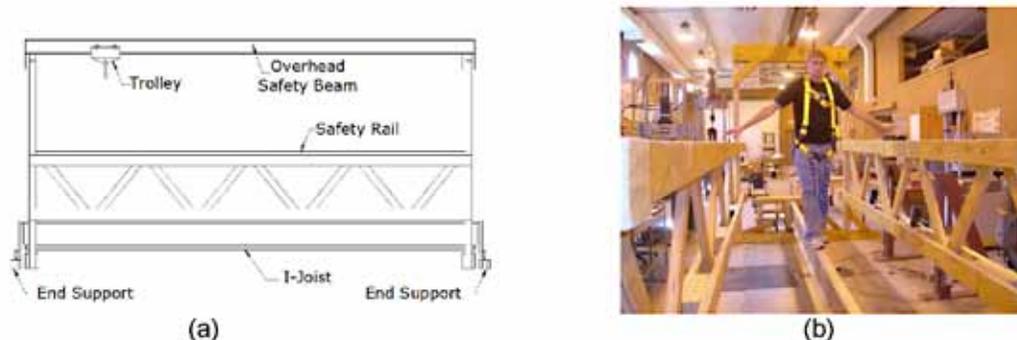

Figure 1: Safety Platform, (a) Side View, (b) Participant Walking on Joist

the potentiometers allowed the calculation of both the lateral displacement and rotation of the joist at these locations. This calculation was based on the assumption that the web of the joist does not deform and remained perpendicular to the flanges. Further details of testing and measurement can be found in Timko [2009].

Results

Figure 2 shows the relationship between the weight of the test subject and maximum induced load on the top flange. A linear regression was fit for each joist type. The J1 and J2 I-joists had similar horizontal forces and regression curves. There was a significantly greater amount of variance within the J3 joist results compared to the other two joist types. The J2 joists were the stiffest joists with respect to lateral and rotational stability,while the J3 joists were the least stiff. From the slope values discussed in Timko [2009], the J1 joist horizontal force averaged 9.3% of static weight, the J2 joist horizontal force averaged 16.1% of static weight,and the J3 joist horizontal force averaged 72.1% of static weight. Previous results from static testing found differences in bending properties of different joist manufacturers [Timko 1999]. However, the effect of different joist manufacturers is confounded with the longer length used for J3. The horizontal force tends to induce buckling at a lower vertical load than if no horizontal force is present. As worker static weight increases,standard equations for vertical loading of joists may over predict the buckling load because the horizontal force is not accounted for.
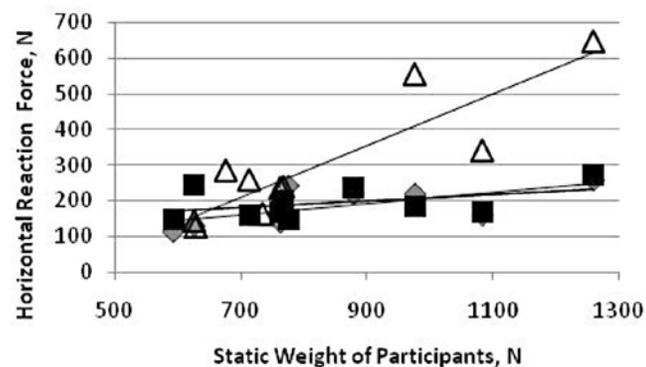

Figure 2: Horizontal Force vs. Static Weight of Participants

Figure 3 shows the relationship between static weight and the top flange deflection of the joist at midspan. Figure 3 shows a similar behavior to Figure 2, where the performance of the J1 and J2 joists was similar while the J3 joist produced much larger deflections. Again, the effects of the different joist manufacturers and joist length were confounded in these results. An analysis of variance of these test results indicated no significant effect was found for the participant static weight or joist type compared to the top flange deflection. No research was found to determine the angle of movement required to induce falls. As the lateral deflection of the beam increases, the opportunity for workers to fall from these joists increases. These results may indicate that overweight workers may be at more risk for falls from elevation from unbraced joists.
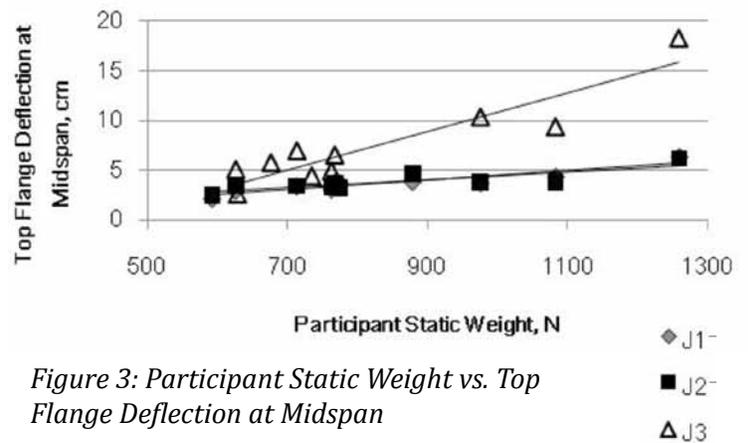

Figure 3: Participant Static Weight vs. Top Flange Deflection at Midspan

Conclusions

This paper describes the measurement of the lateral buckling of unbraced I-joists due to workers walking parallel to the joist direction. As the static weight of a person increases, the amount of horizontal force and lateral deflection of the joist increase. The increase in horizontal force can induce lateral buckling at lower loads than predicted by only considering vertical forces. The increase in top flange deflection creates an unstable surface where the tendency for workers to fall may increase. Lateral buckling of unbraced I-joists may become a more critical for overweight workers due to the dependence on static weight.

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