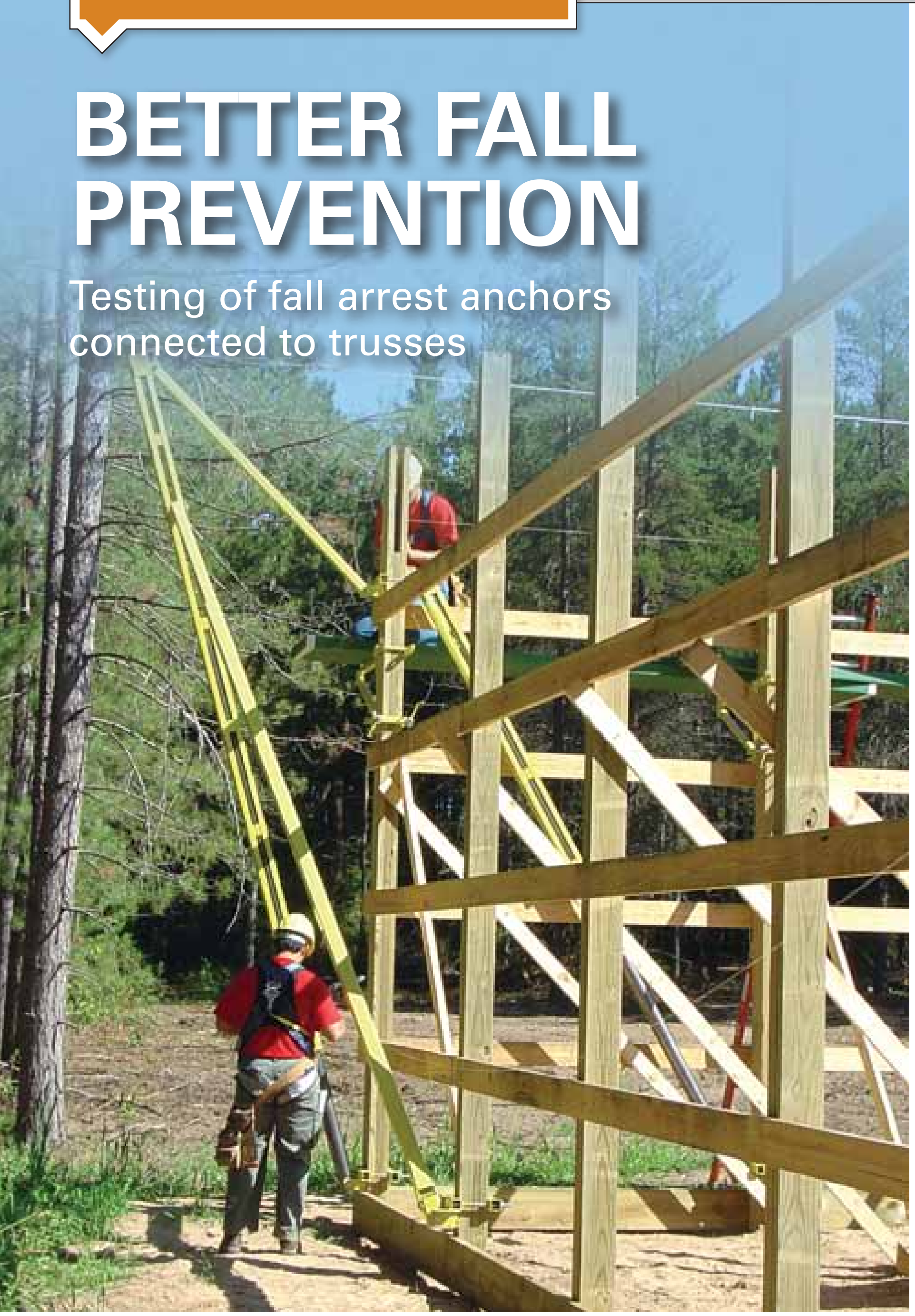
BY DANIEL P. HINDMAN, PH.D., AND LORI M. KOCH, M.S., M.F.

BETTER FALL PREVENTION

Testing of fall arrest anchors connected to trusses



Falls are an ever present hazard on construction sites and account for a disproportionate number of fatalities and injuries on jobsites. In 2010, 635 fatalities were caused by falls (U.S. Bureau of Labor Statistics, 2012). This number represents a decrease in recent years, which is probably due to the changes in the amount of construction work performed. However, from the years 2003 to 2006, as construction work increased, the number of fatalities from falls increased, while fatalities in other major areas (homicides, highway incidents and struck-by incidents) decreased.

Accidents cause severe physical and mental harm to workers, resulting in direct costs (hospital bills, time off work) as well as indirect costs (workers' compensation and higher insurance rates), and lost time (lost time of worker affected, lost time of crew members coping with the accident scene, time to train new crew members). One source estimates that the average direct cost of a workplace accident is approximately $17,000 (Lipscomb, Dement, & Behlman, 2003). This estimate does not include the opportunity costs of falls, including negative press and the loss of reputation in the community and in the industry, which can be much more costly and harder to define. Workplace accidents are negative events — no one involved in the construction project receives any benefit when an accident occurs.

The importance of falls and of understanding proper construction and safety methods was illustrated at NFBA's 2012 Frame Building Expo, where several presenters discussed the implications of changes in fall protection regulation by the Occupational Safety and Health Administration, as well as the care needed when dealing with long-span trusses. Jobsite safety requires constant vigilance and training. At Virginia Tech, our research group has been involved in a long-term project sponsored by the National Institute of Occupational Safety and Health to study the use of fall arrest systems in residential construction.

A previous research and technology article in *Frame Building News* ("Technical Requirements for Fall Protection Systems," January 2011) provided a discussion of fall protection and included equations to calculate the loads that an anchorage for a fall arrest system must carry based on the choice of lifeline and harness. Lifeline and harness products have a set of standard values and are commercially available. The article also discussed research at Virginia Tech that used a fall arrest system from post-frame construction.

Our research has focused on the mechanical strength of the anchors used and the subsequent load path needed to transfer the anchor force through the structure. During construction, truss elements are especially vulnerable to out-of-plane loads (such as those imposed by a safety harness). Although this is a known fact about trusses, almost no scientific studies have been made of the forces that trusses can carry out of plane. The reason for the lack of these studies of out-of-plane loads is that trusses were never designed or intended to carry these loads until bracing and sheathing were attached. Fall arrest presents a "which came first — the chicken or the egg?" scenario. A worker is required to wear a fall arrest harness with an anchor to work at heights over 6 feet, but a worker cannot safely attach an anchor to the roof system until the system is constructed.

Changes in OSHA fall protection requirements

On September 16, 2011, OSHA rescinded the exemption from fall protection for residential construction, including conventional (stick-frame), post-frame and precast concrete construction. Residential construction must now comply with the standards for fall protection used in commercial construction. These provisions include the use of a fall protection system or fall arrest system for workers at heights over 6 feet. An alternative fall protection plan may still be used if a site-specific hazard prevents use of fall protection equipment.

A fall protection system is usually thought of as a passive system such as netting or guard rails. The fall protection system is called a passive system because the workers are not wearing special harnesses or are not attached to the structure. Fall protection systems are typically cost prohibitive to install, inspect and use, given the short time span in which workers install trusses and other roof system elements. In residential construction, it is expected that the time to set up and inspect a net system could be similar to the time to install the roof elements.

A fall arrest system is a three-part active system consisting of a safety harness worn by the workers, a lifeline or energy-absorbing device and an anchorage to a secure location on or off the structure. It is considered an active system because the worker is physically tethered to the structure.

Though fall arrest systems cost less than fall protection systems and take less time to install, they also present concerns, such as whether anchorages are properly designed to ensure that workers can be arrested before striking the next surface (especially in low-rise construction) and before interacting with multiple workers.

Figure 1 Photo from OSHA 2011 guidance document showing a questionable attachment to a wood member.

Maximum load on fall arrest anchors

OSHA 1926:502(d)(15)(i-ii) states, "Anchorages used for attachment of personal fall arrest equipment shall be independent of any anchorage being used to support or suspend platforms and be capable of supporting at least 5,000 pounds per employee attached or shall be designed, installed and used as follows: As part of a complete personal fall arrest system which maintains a safety factor of at least two; under the supervision of a qualified person."

The underlined portion of this statement is often disregarded, yet it is the most critical portion of the statement. The previously cited technical article describes the equations that must be used to design the fall arrest system described. As mentioned in the previous article, the maximum force that a person can experience in a fall arrest is limited to 1,800 pounds by OSHA. Typically, if a shock absorber is used in the lifeline, the force on a person is limited to 900 pounds. Using a safety factor of 2, this is now a force of 1,800 pounds, which is much less than the earlier prescribed 5,000 pounds.

The discussion of the anchorage reveals a short-sightedness about the conditions where fall protection is needed. The anchor may be able to carry this load, but can the structure itself carry these loads to the foundation without causing failure that would cause a fall — or worse? The load path required for the transmission of the force of the fall to the foundation is just as important — or more important — as the strength of the anchor itself.

Attaching anchors to truss systems

The Structural Building Components Association (2011) has produced document B11, "Fall Protection and Trusses," to provide information about fall protection on job sites. This article explicitly shows an image of a worker with a lanyard looped around a truss and a large red 'X' through the picture. However, an OSHA guidance document (2011) titled "Fall Protection in Residential Construction" shows many different methods for compliance with the changes in fall arrest provisions. Figure 1 is a photograph from the OSHA document that appears to show a lanyard wrapped around a wood member. The photo is cropped, so it is impossible to see what the wood member is (e.g., rafter, truss, brace, nonstructural support).

LeBlanc Building Company and Weyerhaeuser conducted some dummy-drop tests of anchors connected to truss systems with correct temporary bracing. These tests can be viewed on YouTube (www.youtube.com) under the title "Truss Feasibility test/demonstration was conducted by Weyerhaeuser Research & Development." If temporary bracing is correctly attached and five trusses are used, the structure can withstand the load of a dummy falling. The use of several different bracing methods (metal connectors vs. studs) was also shown in the video. This testing demonstrates that larger

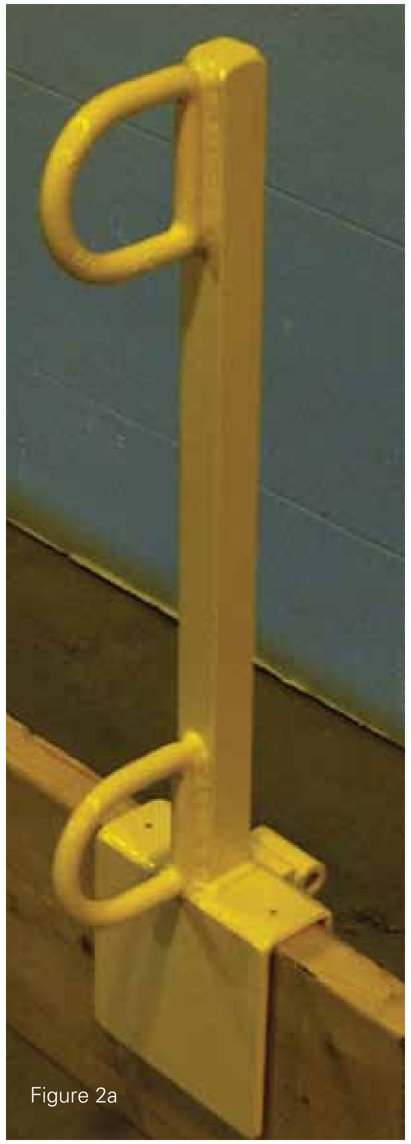


Figure 2a

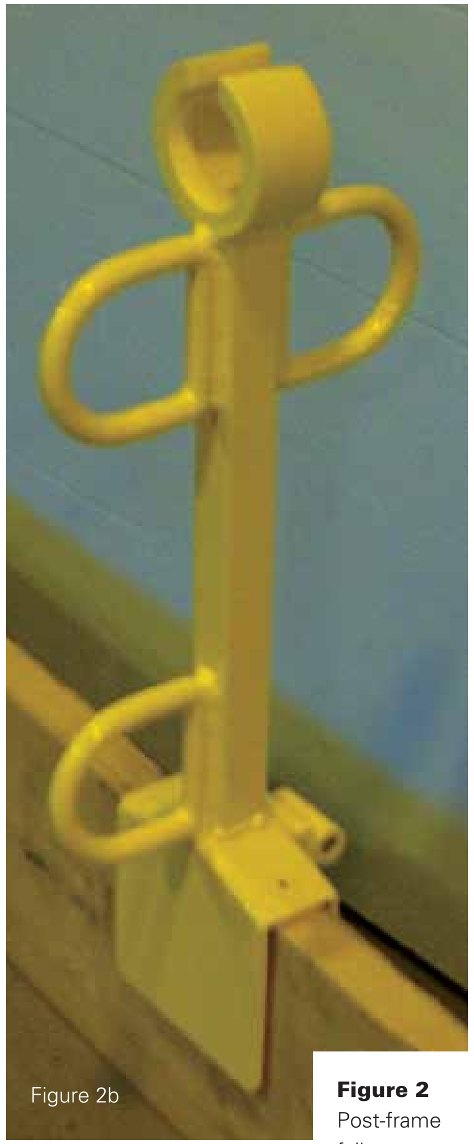


Figure 2b


Figure 2c

Figure 2 Post-frame fall arrest system: (a) eave bracket, (b) peak bracket, (c) sheathing bracket

assemblies can carry the load of a worker falling, but the question of how the first five trusses are set and braced before an anchor can be safely attached remains.

Current research at Virginia Tech

Recently, Daniel Hindman and another Virginia Tech researcher, Tonya Smith-Jackson, were awarded a NIOSH grant to study the use of personal fall arrest systems in construction. Smith-Jackson is a professor in the Industrial and Systems Engineering Department who specializes in understanding the attitudes of workers toward their jobsite and surrounding conditions. Successful safety programs in the past have influenced workers to change attitudes in order to use safety equipment. Several authors have suggested a measure of safety culture that includes attention to workers' attitudes and impressions about safety as well as to differences in the attitudes toward safety held by other peers or employers.

The focus of this project was to develop a fall arrest system for residential construction. The inspiration for the project was a safety lecture presented at NFBA's 2008 Frame Building Expo by Wick Buildings, Brickl Brothers, FBi Buildings and Finger Lakes Construction on the use of fall arrest systems. In particular, Wick Buildings and Brickl Brothers had worked to develop a fall arrest harness bracket that could be attached to trusses to provide a continuous fall arrest system during construction.

The photographs in Figure 2 show three different anchors used. The first two anchors, (a) and (b), are attached to the eave and peak of the truss, respectively. These anchors can be installed on the first truss before it is lifted into position. The third anchor, (c), is used when sheathing is applied to the trusses.

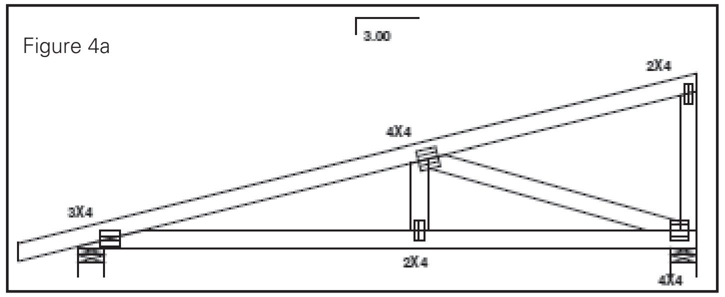
The purpose of this project was to examine the post-frame fall arrest system (PFAS) and develop a residential construction fall arrest system (RFAS). The RFAS would incorporate the best elements of the PFAS, while being easily usable. The mechanical strength of the PFAS and both the mechanical strength and usability of the RFAS were evaluated in this study.

RESEARCH & TECHNOLOGY

Figure 3 Horizontal application of load test (HALT), with test truss mounted using eave bracket

To test the mechanical strength of both the PFAS and the RFAS, a new test machine labeled the HALT (horizontal application of load test) was constructed (see Figure 3). The HALT uses a hydraulic cylinder placed in a vertical position (it is inside the steel frame at left but not visible in the picture) to pull on a steel cable threaded through a series of pulleys. The pulley closest to the truss can be moved up and down the steel frame so the anchors can be tested horizontally at varying positions along the trusses. The cylinder has a maximum capacity of 7,000 pounds and a maximum distance of travel of 20 inches. The HALT is attached to a set of two 2x6 stem walls placed 10 feet apart. The HALT load point is located approximately 18 inches from one wall end to place the maximum load possible on a single connection, representing a worst-case failure load.

Figures 4a and 4b are diagrams of the trusses fabricated by a local truss manufacturer. Because of the small span used, monoslope trusses of 3:12 and 6:12 pitch



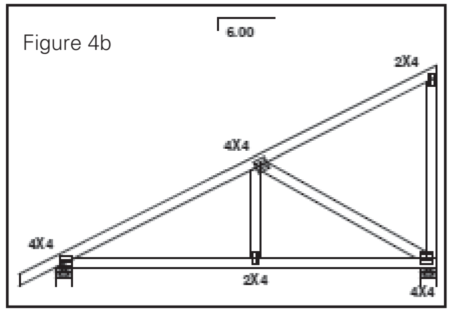


Figure 4 Trusses used for testing: (a) 3:12 pitch; (b) 6:12 pitch

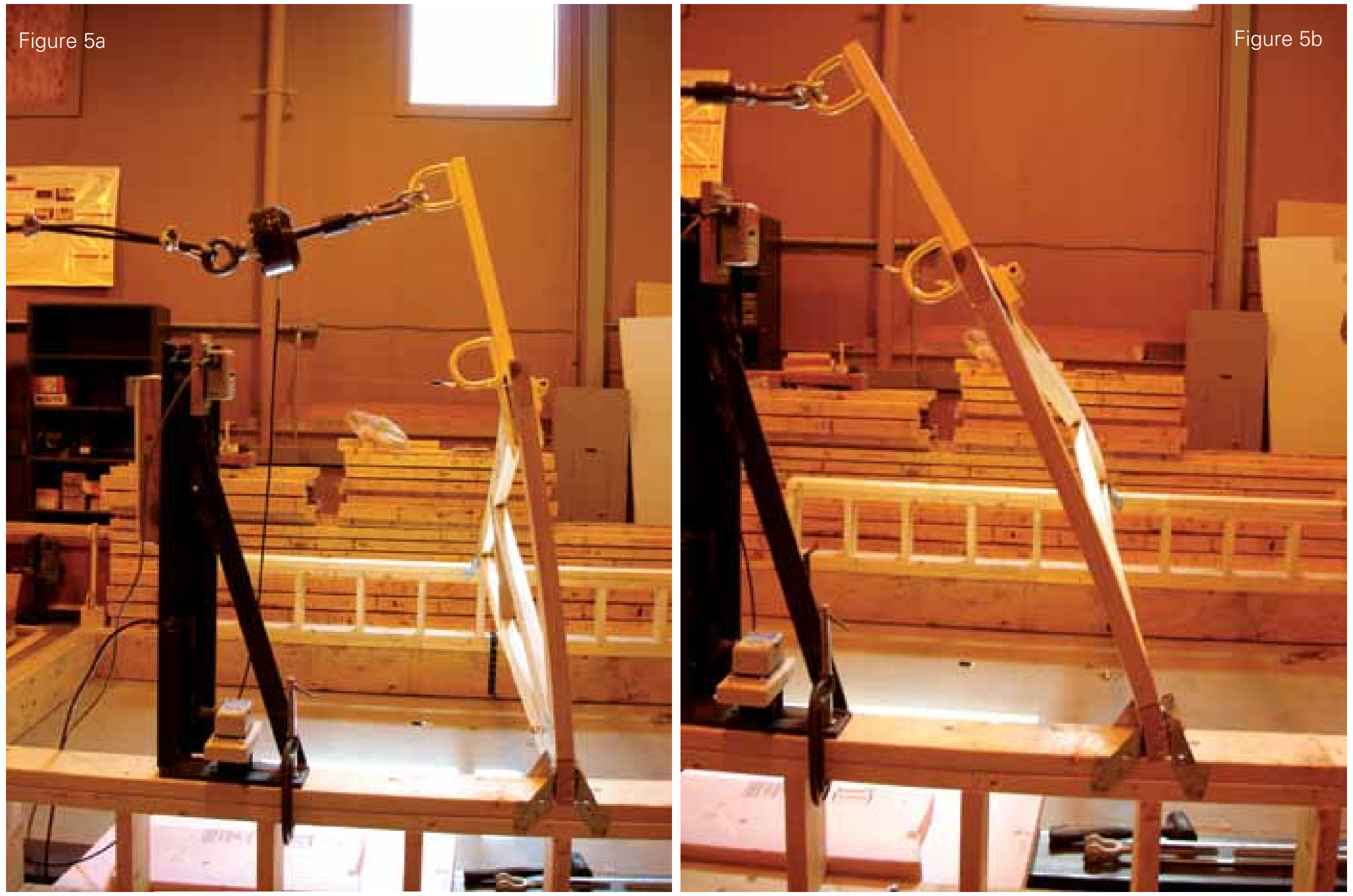


Figure 5
Sequential testing of loading showing anchor attachment to truss (eave bracket)

were used. Trusses were constructed of No. 2 Southern pine 2x4 lumber for all members. Trusses were attached with a set of truss bracing enhancers that were chosen because of the lateral load capacity of these connections. Typical hurricane straps were not considered useful for this out-of-plane loading. The anchors (Figure 2) were attached to the truss using two 8d nails driven through holes on the top face of the anchor. In practice, a ratchet strap is also used to attach the anchor but was not used here in order to provide a worst-case situation. Both types of trusses were loaded at the peak and eave for 3 repetitions each. All trusses were loaded at 1 inch per minute until failure occurred. Lateral deflections of the heel of the truss and peak were measured by linear potentiometers.

The photographs in Figure 5 show the loading of a truss at the peak. The large black cylinder is a load cell placed near the bracket.

Two different failures were observed from the truss testing. If the nails connecting the truss bracing enhancer to the wall did not go through the truss plates, the bottom chord failed in a brittle manner due to torsion generating perpendicular-to-grain stress. Figure 6 shows the torsion failure with a large crack forming at the top row of fasteners in the truss bracing enhancer, just below the truss plate. The location of this failure does not appear to be directly related to the location of the PFAS anchor, as it appeared in specimens with the bracket mounted at the peak as well as the eave.

If the truss bracing enhancer fasteners overlapped the truss plates, the reinforcement of the truss plate prevented brittle failure due to torsion. The failure mode changed to a ductile failure of the truss bracing enhancer itself where the bracket rotated the fasteners in the top plate of the wall. Figure 7 contains two photographs of the ductile failure of the truss-wall connection, showing the rotation of the truss and the lifting of the back side of the truss bracing enhancer off the top plate.

Loads for the connections ranged from 130 pounds to 500 pounds, depending on the type of truss and location of the fall arrest anchor. Higher loads were observed for the eave anchors than for the peak anchors. The increased moment arm of the peak anchors (Figure 2) above the wall connection reduced the capacity of the assembly by more than half. The types of failures noted above did not seem to affect the loads.

None of the truss failures involved the failure of the anchor bracket or top chord. After repeated testing, some spreading of the bracket channel that fits over the truss was observed after 6–7 tests to failure were conducted. From this testing, we can confidently conclude that no one should anchor a fall arrest harness to a single truss element. The single truss elements do not have the structural capacity to arrest a fall, and the possibility of brittle failure could cause the truss to break away from the rest of the structure.

At this time, we are still conducting testing on the 6:12 trusses. We also plan to do other studies using trusses, including these:

- The effects of bracing multiple trusses (2 trusses, 3 trusses, 4 trusses, 5 trusses)
- The effects of changing the speed of loading (the cylinder has a maximum speed of 20 inches/minute)
- The testing of rafters and trusses for comparison (rafters would decrease the cost of materials and storage space).

Preliminary conclusions

This project focused on the testing of fall arrest anchors attached to trusses at various locations. Testing of single truss elements has shown that single trusses are not adequate to carry a fall arrest anchor. This is a very dangerous situation that may include brittle failure of the truss, depending on the connection to the wall. Failure is caused by perpendicular-to-grain stress due to the torsion of the truss around the anchor.

The load path of the anchor is more important than the strength of the individual anchor itself and is one of the complexities of fall arrest systems. Factors affecting the load and load path include the shape of the truss, the position of the loading (i.e., which way the worker falls), the connection point and orientation of the PFAS anchor to the truss, and the type of connector used to attach the truss to the wall. Full results of this testing will be presented in the future, and further testing to establish the effects of brac-

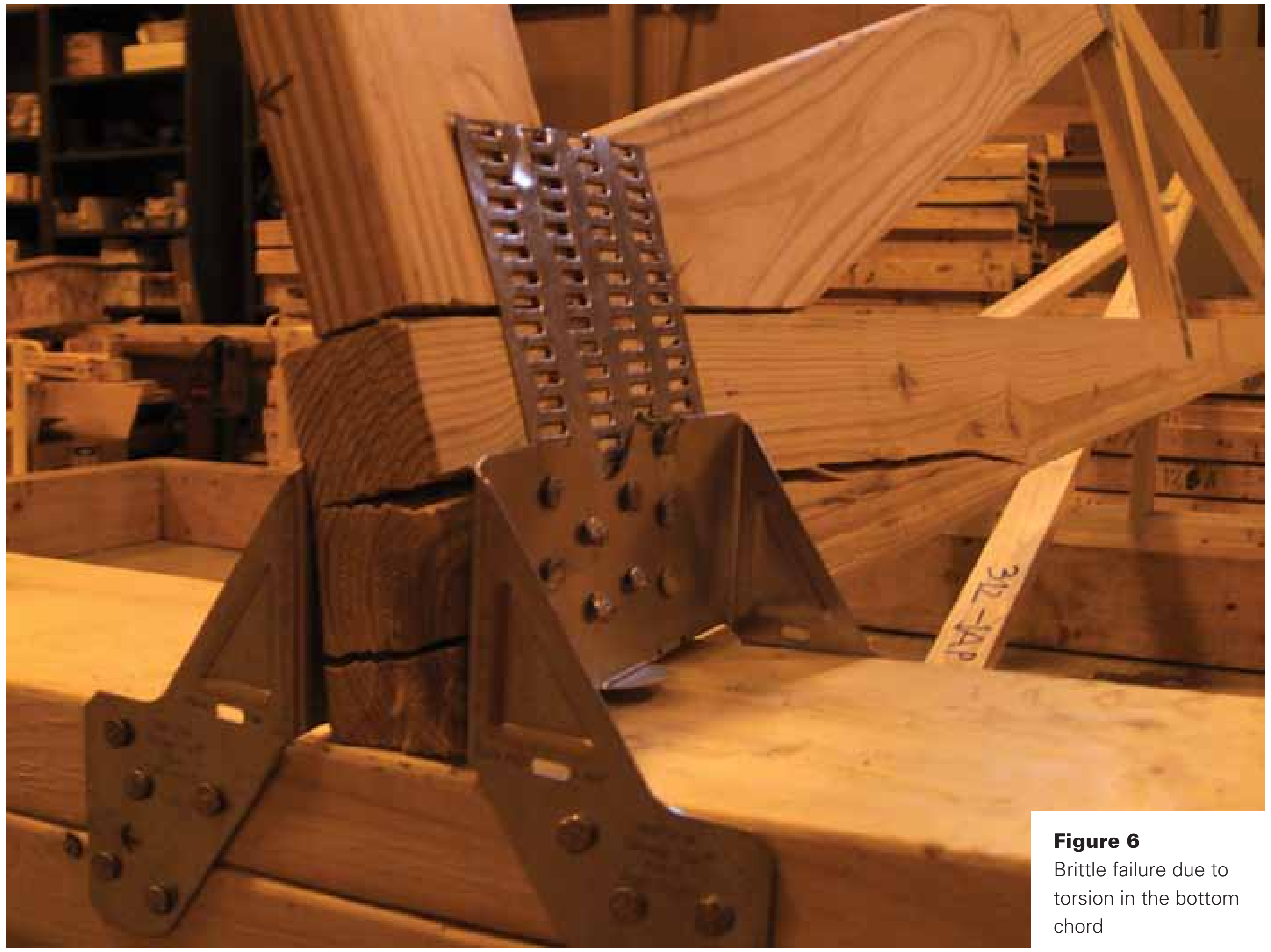


Figure 6
Brittle failure due to torsion in the bottom chord

Figure 7a

Figure 7b

Figure 7
Ductile failure of truss-wall connection showing yielding of connector

ing multiple trusses, establish the effects of loading speed and compare the capacities of rafters to the capacity of trusses will also be conducted in the summer of 2012.

Acknowledgments

This project was made possible by members of NFBA who contributed their time and effort to developing these anchors. A special thanks is extended to those at Brickl Brothers for all of their past help with our questions. This project represents a great partnership where academia can help collect the best practices of industry and publicize those practices to other groups that could use this help. This project also serves as a training program for future designers and engineers who are working toward their B.S. and M.S. degrees at Virginia Tech. The findings of this further research will appear in future articles and presentations. We also welcome any comments or feedback about our research and ways to improve it. ***FBN***

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