

# Personal Fall Arrest System Anchors in Residential Construction

*Daniel P. Hindman, Ph.D., P.E, Justin Morris, Milad Mohamadzadeh, Lori Koch, Joseph Angles, Tonya Smith-Jackson, Ph.D., CPE*

## Introduction

A fall is one of the most traumatic events that can happen on a jobsite. The effects of a fall, much like a wave spreading from a pebble dropped in a pond, can radiate through the work crew, the construction company, the worker's family, a community, or even extend to become a national event. Falls cause great injury, requiring time for personal recovery, as well as psychological stress on other crew members and loss of confidence in the construction company throughout the professional community. We want to personally stress how crucial fall prevention and fall protection are to every construction professional. To reiterate, the effects of a fall can include:

- Economic loss of productivity and site time
- Increases in workers compensation and health insurance
- Bad press, causing a loss of future business
- Loss of respect of other construction professionals

The current landscape for fall protection in residential construction has radically changed. Previous enforcement of fall protection was minimal and only as seen fit on the construction site. Now, the changes to OSHA provisions indicate that fall protection MUST BE CAREFULLY THOUGHT OUT AND PLANNED. The changes have not come without confusion, and have generated concerns of compliance from many builders.

## *Danger of Falls in Construction*

Falls from elevation are one of the most common workplace accidents among construction workers. The Bureau of Labor Statistics (2011) reported during 2010 that 34.1% of workplace fatalities for construction workers were a result of falls. Roofers are at especially high risk, being six times more likely than the average worker to suffer a fatal occupational injury, with 75% of these falls being fatal (Hsiao and Simenov 2001). While statistics are not available, residential construction has several aspects that create greater fall risks than commercial construction, including less jobsite safety regulations,

non-union labor with less opportunity for training, and rapid project turnaround with little time for inspection (Kaskutas et al. 2009 ). From anecdotal evidence, there is a lack of understanding of fall protection needs for residential construction, even among safety professionals.

## *Purpose of Paper*

The purpose of this paper is to provide technical knowledge related to the use of personal fall arrest systems in residential construction. One specific area of concern is fall arrest systems connected to metal plate connected wood trusses. Wood trusses have been specifically designed to carry planar vertical loads, but are not equipped to resist out-of-plane lateral loads. This paper will review previous and current OSHA fall protection guidelines, discuss some of the confusion over the changes, and provide technical information to assist in the calculation of anticipated fall arrest anchor forces including recent research measuring the strength of wood truss roofs to carry fall arrest anchors. This research is part of an on-going National Institute of Occupational Safety and Health (NIOSH) grant to study the strength and usability of fall arrest systems for residential construction.

## **Literature Review**

### *Changes to Fall Protection Guidelines for Residential Construction*

Prior to June 2011, residential construction workers were exempted from OSHA requirements with regards to fall protection systems. Due to the lack of compliant fall protection products on the market aimed at residential construction as well as lack of knowledge by construction firms, OSHA extended the deadline for compliance to March 15, 2013 (Miller 2013). Under the new regulations, all residential construction workers working 6 feet or more over a lower level are required to have either a guardrail system, net or a personal fall arrest system (OSHA 2011a). For residential roofing work, guardrail and net systems were considered impractical

due to setup time by the investigators. Therefore, this paper focuses on the use of personal fall arrest system.

A personal fall arrest system (FAS) is an active system (i.e., connected to the worker), comprised of three parts: anchorage, lifeline/lanyard, and harness. Harnesses and lifeline/lanyards are standard products used in both residential and commercial work that are widely available. While FAS use has been common in commercial construction for some time, use in residential construction has been limited. Concerns have arisen on anchorage designs for residential roofs.

The Occupational Safety and Health Administration (OSHA) sets forth the requirements for Fall Protection Systems in OSHA 29 CFR 1926.502(d)(15) (OSHA 2011b), stating:

*1926.502(d)(15) Anchorages used for attachment of personal fall arrest equipment shall be independent of any anchorage being used to support or suspend platforms and capable of supporting at least 5000 lbs (22.2 kN) per employee attached, or shall be designed, installed, and used as follows:*

*1926.502(d)(15)(i) As part of a complete personal fall arrest system which maintains a safety factor of at least two; and*

*1926.502 (d)(15)(ii) Under the supervision of a qualified person.*

Additionally, in OSHA 29 CFR 1926.502(d)(16)(i-ii), the maximum arresting force on an employee is limited to 1800 lbs for those wearing a body harness. Therefore,



**Figure 1. Figure 24 from OSHA Guidance Document As Presented (OSHA 2010)**

maintaining a safety factor of two is possible with an anchorage capable of supporting only 3600 lbs.

#### *Guidance Document From OSHA*

To aid in the understanding of the recent changes in fall protection guidelines, OSHA has produced an *OSHA Guidance document Fall Protection in Residential Construction* (<http://www.osha.gov/doc/guidance.html>) which illustrates many products and methods which are assumed to comply with the new fall protection guidelines. While the concept of this document is helpful, the authors feel that what has been produced by OSHA represents little more than a product showcase. No technical information as to the capacity of particular anchors or fall arrest system configurations is given, and no direct statement of product compliance or non-compliance is given.

Several of the images shown could be misinterpreted. For example, Figure 24 in the guidance document (reproduced below as Figure 1) shows a self-retracting lifeline attached to a wooden member. However, the image is cropped so closely that the type of wood member (i.e., truss, temporary bracing, stud framing) cannot be identified, nor can the connection of the wood member to the surrounding structure. This image illustrates one of the most important concepts of fall arrest systems – The strength of any fall arrest system anchor is dependent upon the attachment to the structure and the development of an adequate load path.

Most fall arrest anchors claim to support 5,000 lbs or more. The authors agree with these claims related to the anchors themselves. However, the strength of the wood members used in residential construction must be determined for each individual element and loading. Unless a static load is oriented vertically downward, there are very few wood members in residential construction that can support 5,000 lbs. The use of a designed fall arrest system (See OSHA 29 CFR 1926.502(d)(15) above) is needed for wood construction and correct detailing of the anchorage connection is required.

As scientists and engineers, the authors have been seeking sound technical information on which to base decisions about the use and attachment of fall arrest anchors to residential wood construction. The calculation of fall arrest loads has been discussed by Ellis (2012) in *Introduction to Fall Protection*. A set of equations are provided for calculating the vertical fall arrest load and horizontal lifeline fall arrest load that would be experienced by a worker. These equations account for the material of the lifeline, the distance fallen before the FAS engages, and the effect of a shock absorber (Ellis 2012). To the authors' knowledge, this calculation procedure appears to be the only technical information found to fulfill the requirement of a 'designed fall arrest system'. Multiplying the result of the vertical fall arrest load by two should provide an estimate of the maximum forces required by the fall arrest anchor. Interpretation of these results should be conducted by a qualified person using the specific design parameters for the fall arrest system used.

Assuming the use of a self-retracting lifeline (reduces

free fall distance to 2 feet or less), the calculated fall arrest load for a single worker ranges from 375 to 750 lbs, or 750 lbs to 1500 lbs with a safety factor of two. These values are much lower than the 3,600 lbs or the 5,000 lbs previously discussed. The use of these lower loads is another point of confusion common in the OSHA guidelines. Now that the needed load for a fall arrest anchor has been determined, testing is still needed to determine if fall arrest anchors attached to roof trusses can be used to carry this load.

## Methods

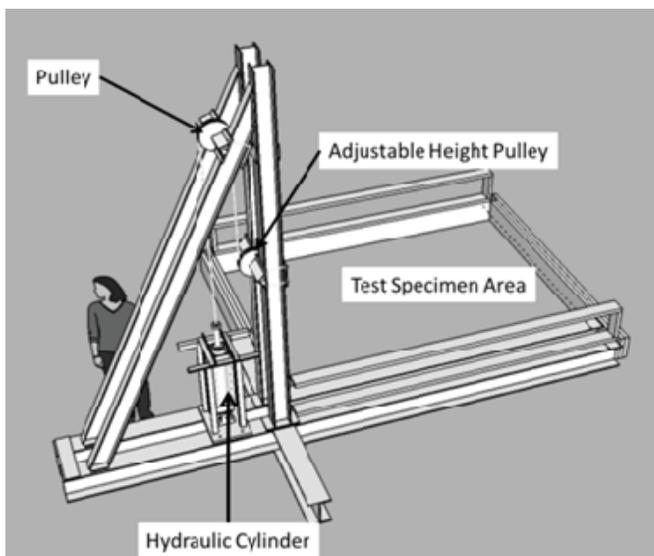
### *Description of scaled world methods*

Since the observation of construction site hazards is dangerous and would impede construction progress, a simulated construction environment was created in the Wood Engineering Lab at Virginia Tech. The concept of a scaled world allows the sampling of realistic variables in a controlled environment where measurement opportunities exist while hazards and extraneous site variables are eliminated. The scaled world concept has been previously used in computing and other disciplines.

The worst case loading of the truss system due to a worker falling is a horizontal load applied out of the truss plane (i.e., falling off the gable end) similar to the environmental loads discussed by Bohnhoff (2001). This load direction is the most severe stress placed on the truss and represents a load that residential metal plate connected wood trusses are not designed for, but is possible due to a worker falling.

### *Horizontal Application of Load Tester (HALT)*

A specially designed test fixture was created to load truss roof systems by a horizontal load, called the Horizontal Application of Load Tester (HALT) (Figure 2). The HALT has a steel vertical and horizontal frame supporting a ver-



**Figure 2. Diagram of the Horizontal Application of Load Testing (HALT) with Stem Walls Positioned for Eave Loading**

tically oriented hydraulic cylinder integrated with an adjustable pulley system. An adjustable pulley can be moved vertically to change the location of load application to the roof system, either horizontal or at an angle. The hydraulic cylinder has a 20 inch long travel and is controlled by an integrated data acquisition system. A ½ inch diameter braided steel cable connects the cylinder to the test specimen, through a series of pulleys. The cable attachment to the truss system contains an integrated 10,000 lb load cell. A set of two stem walls were constructed at the truss support points to represent the wall connections below the trusses. These stem walls were attached to the self-reacting portion of the HALT frame to prevent uplift. Stem walls were sheathed on one side to prevent racking.

A variety of different tests have been conducted using the HALT frame. Each test has attempted to explore different aspects of the fall arrest anchor strength related to truss roof systems. The following sections describe a variety of tests which have been conducted.

### *Fall Arrest Anchor Used For Testing*

The fall arrest anchor used for all truss testing is shown in Figure 3. This bracket, called the post frame fall arrest system (PFAS) was adapted from use in post frame construction. Originally, this bracket was observed by Dr. Hindman at the 2008 Frame Building Expo and was one of the ideas for the subsequent proposal of this work. The PFAS anchor, along with other elements of a fall protection system, was presented by several post frame builders as an 'open source' fall arrest equipment, where the PFAS anchor was offered at cost of manufacture.

### *Monoslope Truss Testing*

Initial testing of single trusses used a monoslope truss with 3:12 and 6:12 pitches (Figure 4). At the time of testing, only trusses 10 feet in span could be tested with the HALT. The monoslope configuration was thought to give a worst case scenario of testing at the truss peak to produce greater moments in the trusses. Monoslope trusses



**Figure 3. PFAS Anchor Used for Testing**

were tested at 1.0 inch/min of displacement to prevent sudden failure. All trusses were attached to the stem walls of the HALT by truss bracing enhancer (TBE) connections, which had greater stiffness than hurricane ties and a defined lateral load value.

The ultimate load of various testing at the heel and peak of the monoslope trusses are summarized in Table 1. Greater loads were found at the heel of the truss, rather than the peak. All loads were low compared to the loads needed for a fall arrest anchor given above. Therefore, no fall arrest anchors should be attached to a single truss in residential construction. The height of the PFAS anchor itself increased the moment placed on the peak connection. Failure of all monoslope trusses was attributed to rotation of the truss-wall connections due to the rotation of the truss out of plane (Figures 5 and 6).

*Kingpost Truss Testing*

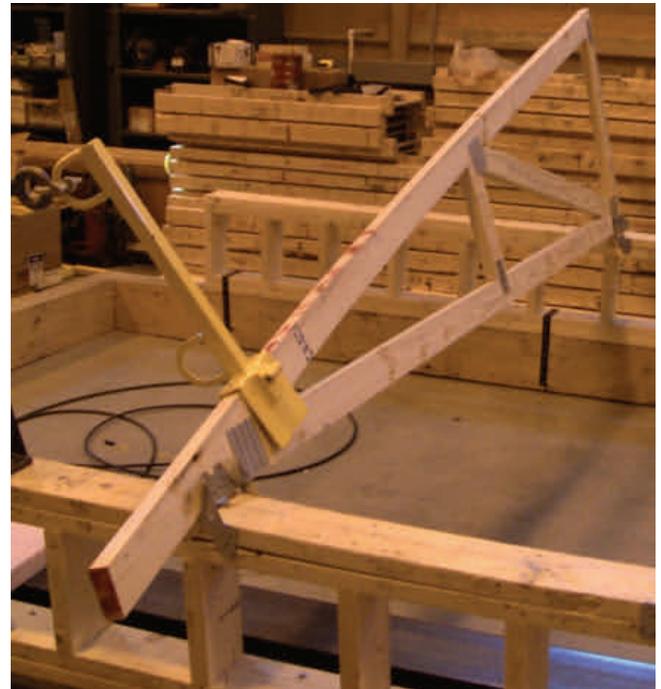
A set of kingpost trusses with a 13 foot span and a 4:12 pitch was used for the next test. This truss is relatively small compared to most trusses used in construction, and contains only a single web in the center. At present time, the 13 foot span is the largest that can be tested on the HALT. Trusses were installed at 2 feet on center using conventional hurricane ties. Load was applied at the peak of the truss (midspan between the walls).

*Displacement Rate Testing*

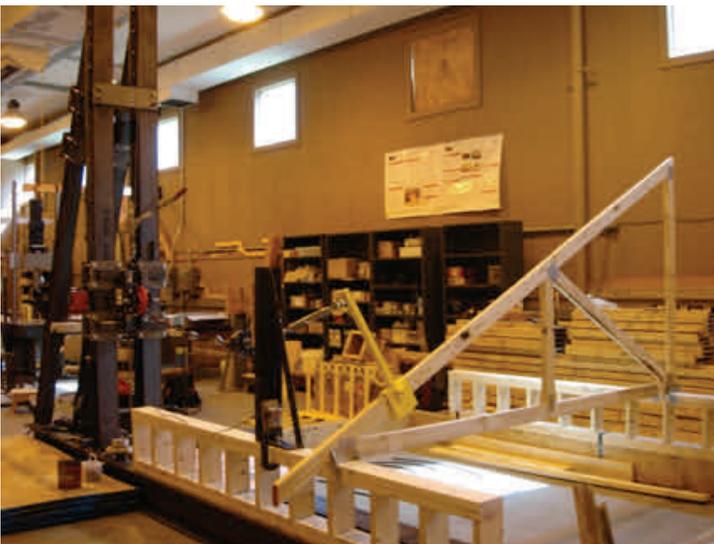
Displacement rate loading of wood members has a decided effect upon the strength of wood members. Previous testing of monoslope trusses used a relatively slow speed to prevent catastrophic damage of the truss. However, falls from trusses usually occur as sudden, uncontrolled loads. This test examined the effect of displacement rate on the ultimate load of trusses. Two kingpost trusses were connected by blocking elements along the top and bottom chords and loaded by the HALT at 1.0 inch/min,

**Table 1. Ultimate Load Results of Single Monoslope Truss Testing**

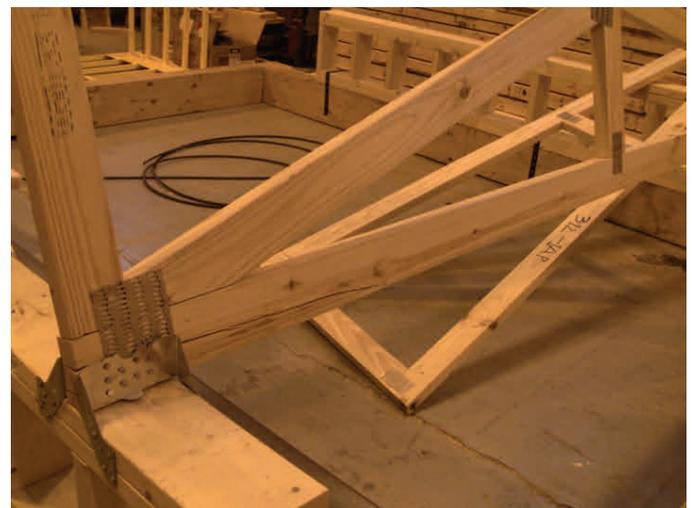
Slope	Position Where Load Applied	Ultimate Load, lbs
3:12	Peak	125
	Eave	417
6:12	Peak	78.3
	Eave	375



**Figure 5. Rotation of Truss At Truss-Wall Connections Due to Lateral Loading**



**Figure 4. Testing of Monoslope Trusses Using HALT**



**Figure 6. Fracture of Bottom Chord of Truss Due to Lateral Loading**

2.0 inch/min, 5.0 inch/min, 10.0 inch/min, 15.0 inch/min, and 20.0 inch/min.

Ultimate load values from the change in displacement rate are shown in Table 2. Load values ranged from 121 lbs. to 149 lbs., demonstrating that little effect of displacement rate. Figures 7 and 8 show the progressive failure of the trusses observed at each displacement rate. The majority of the movement of the truss was related to withdrawal of bracing nails and rotation of truss-wall connections. Since no diagonal bracing was used, the movement of the trusses was much greater than what would be expected with proper diagonal bracing in place. Since the withdrawal of steel fasteners from the wood members was the main type of failure, the viscoelastic effects of wood strength did not appear to change the maximum load over the range of displacement rates tested.

Comparisons were also made to impact tests, where a load of 165 lbs. was dropped. Video footage showed the same failure of the impact loaded trusses as the displacement loaded trusses using the HALT. The use of fixed displacement rate by the HALT allows detailed observation of load-displacement rates as well as the observation of progressive failures, both of which cannot be measured during an impact test. Therefore, the speed of future testing was increased to 15 inches per minute to provide a shorter test duration, but allow adequate collection of data points.

Note that the loads of the two truss configurations from the displacement rate testing had very low load values compared to the values required for the fall arrest anchors described above. This testing showed that two trusses without diagonal bracing have very little resistance to lateral loads.

*Effects of Different Bracing*



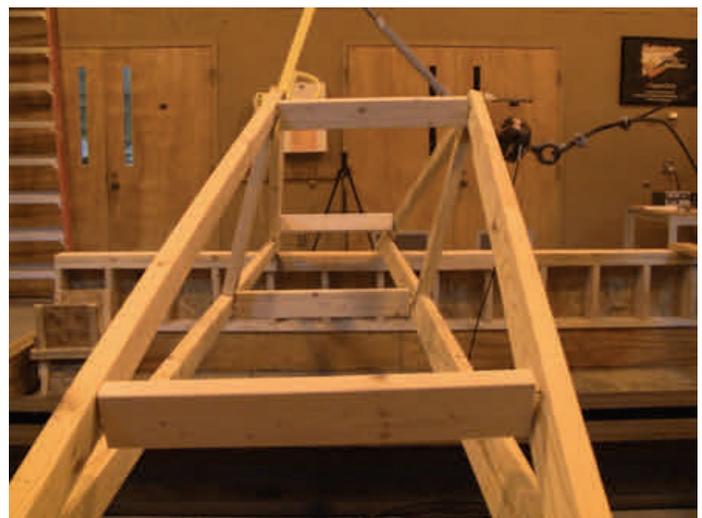
**Figures 7. Initial Alignment of Displacement Rate Trusses**

**Table 2. Ultimate Load Results of Displacement Rate of 13 Foot Kingpost Trusses**

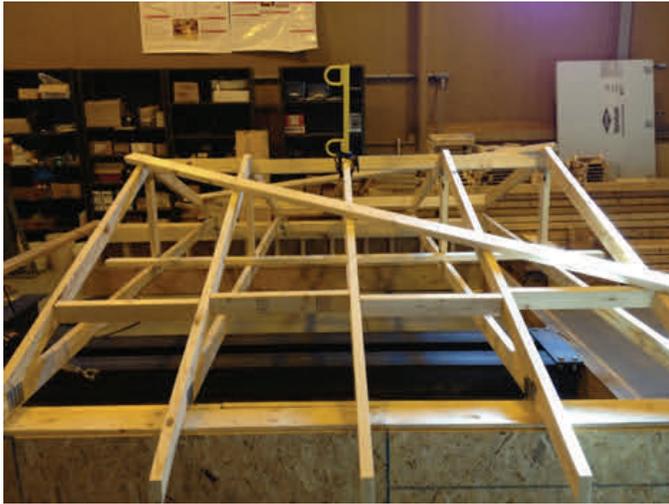
Displacement Rate, in/ min	Ultimate Load, lbs
1.0	124
2.0	121
5.0	123
10.0	149
15.0	142
20.0	147

A separate set of kingpost trusses were tested to examine the effect of different bracing patterns used. A group of five kingpost trusses were assembled each at 2 feet on center. Lateral bracing was applied using one of three methods: blocking, bracing over the top of the truss, and a metal engineered brace. Diagonal support along the top side of the trusses was also used (Figure 9). The PFAS anchor was used for the testing of the three braces. Displacement was applied at a rate of 15 inches per minute.

The ultimate loads from testing are shown in Table 2. Wood blocking values ranged from 726 to 752 lbs, while the metal engineered brace supported 571 lbs. The height of the bracket imposed an additional moment arm upon the top of the truss. Failures of the truss system resulted from twisting of the central truss where the PFAS was attached, as well as several of the braces loosening as the truss system deflected. The blocking between truss nails withdrew from the truss member (Figure 10). The top bracing nails did not pull out, but some splitting of the truss top chord was noted where



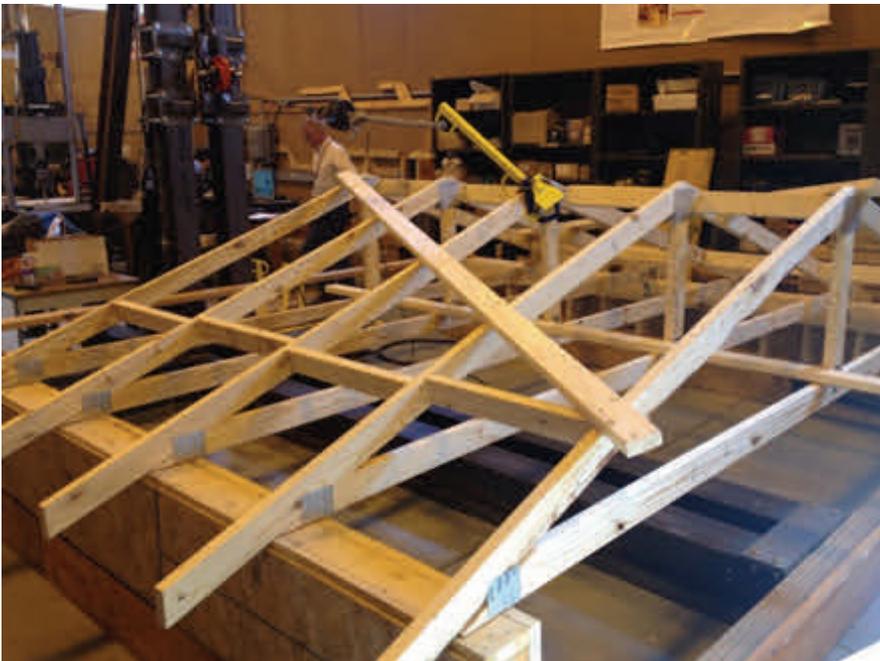
**Figure 8. Displacement Rate Trusses During Loading**



**Figure 9. Five Kingpost Truss System Used for Bracing Testing**

the bracing nails were inserted (Figure 11). The metal engineered bracing allowed the structure to bend, but after experiencing too much out-of-plane movement, the teeth holding the brace in popped out of the truss (Figures 12 and 13).

The metal engineered brace had a tooth design similar to a truss plate. As the trusses began to deflect, stresses placed on the braces tended to compress the braces, which applied an uplift or prying force to the brace. Since the ultimate loads are at the lower bound of the range of fall arrest anchor loads predicted by the equations given above, the use of the PFAS anchor in residential construction is not recommended. Further testing of different anchors is ongoing.



**Figure 10. Five Truss System with Blocking Showing Bracing Pullout Near PFAS**

**Table 2. Ultimate Load Results of Different Bracing Testing Using PFAS on Five 13 Foot Kingpost Trusses**

Bracing	Ultimate Load, lbs
Blocking Between Trusses	726
Top Bracing Over Trusses	752
Metal Engineered Brace Between Trusses	571

The increase in strength in the five truss system was due to the system behavior of the group of trusses, where load was transferred between trusses, rather than being contained in a single element such as the previous monoslope testing. This system concept is illustrated well in Figure 13, where rotation is noticeable in several trusses.

The loads for the top bracing of trusses with the PFAS anchor met the previously discussed load range of 750 to 1500 lbs in order to carry a fall arrest anchor with a self-retracting lifeline. Testing of different fall arrest anchors which enhance the ability to spread load across multiple trusses may further increase this load value and help provide important technical data on fall arrest system design for residential construction.

**Conclusions**

In designing fall arrest systems for residential construction, it is important that safety professionals considered the entire load path of the fall arrest system through the structure. All connections of the fall arrest system to truss members and the wall below should be scrutinized to develop the loads that fall arrest anchors can carry. A single truss of any design in residential construction should never be used as a point of attachment. The testing of fall arrest systems shown here just reached the allowable load range recommended for residential construction anchors with self-retracting lifelines attached. An important point observed is to spread the load across a series of trusses to ensure that no single member is overstressed. It is important that all fall arrest systems attached to trusses be designed by a qualified individual for the particular construction situation present.

**Acknowledgement**

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**Figure 11. Loading of Five Truss System with Over the Top Bracing and Splitting of Truss Top Chord At Center**



**Figure 12. Metal Engineered Bracing Pulled From Truss After Failure**

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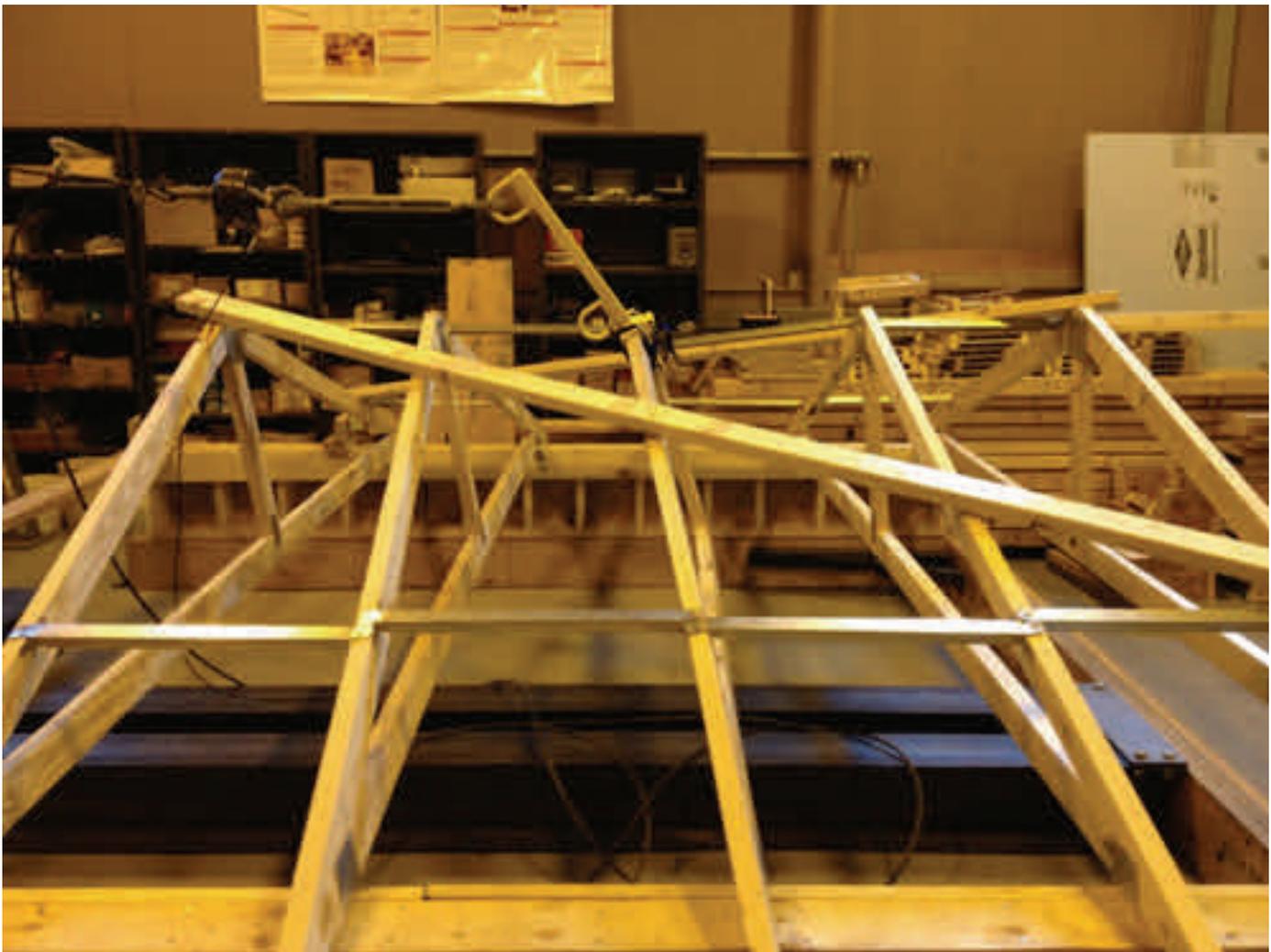
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**Figure 13. Loading of Five Truss System with Metal Engineered Bracing**

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In The Next Issue:

Residential Wood Decks

*Wood Design Focus* has always provided current industry information. Most topics in this journal have discussed technical aspects of design and the use of wooden building construction. As we design and construct buildings, engineers and architects often tend to focus on the materials and methods of construction. However, the moving forces behind these materials and methods – notably the human workers – often receive little attention. Construction safety is one of the most important worker issues. Conducting work in a safe manner affects worker productivity, worker attitudes and overall worker health. Many times, the discussion of human and structural loading related to construction safety is forgotten or relegated to a lower position.

I began conducting safety-related research about eight years ago. Initially, I was invited by a colleague to contribute to a proposal for a NIOSH safety center. That center has now evolved into the Center for Innovation in Construction Safety and Health (CICSH), under the Occupational Safety and Health Research Center (OSHRC) through Virginia Tech. My colleague challenged me to think differently about my research. How can the understanding of the mechanics of wood influence the safety of construction workers?

I began looking at the effects of lateral buckling of wood composite I-joists as a possible initiator of falls from elevation. At this time, I began to grasp the current severity of falls in construction. Other researchers have gone so far as to call the number of fatalities an epidemic. As I continued pursuing safety research, I began to realize how useful the design of wood structures is to the safety field. Currently, I am the lead investigator in a project examining the use of personal fall arrest systems in residential construction, which is described in this issue. I also currently serve as the Co-Director of the Center for Innovation in Construction Safety and Health (CICSH).

I find myself explaining to both engineers and safety professionals (even once to my department head) why I am researching safety and the importance of involving engineers. One of the important aspects called Prevention Through Design (PtD) directly involves the re-design of buildings to create inherently safer work environments during construction and after construction. There is a genuine need in safety for the innovation and creativity that structural engineers and architects possess. The intersection of safety and engineering is an exciting area of study – combining experimental mechanics, human factors, experimental design, industrial psychology and building construction.

This selection of authors represents a variety of researchers and professionals looking at the intersection of safety and engineering. These articles can help promote worker safety, which ultimately improves worker productivity and health. This issue of *Wood Design Focus* is part of a two-year Falls Campaign effort to bring attention to the problems associated with falls from elevation. More information is available at <http://www.stopconstructionfalls.com>. I hope you will be inspired by these articles. As always, we have provided contact information for the authors if you have questions or desire more information.

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