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FALL ARREST SYSTEM TESTING

Lessons for Post-Frame Construction

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

A growing interest in fall protection is currently being spurred on by changes in regulations for light-frame residential construction. The entire construction industry faces increased scrutiny, and those working in the industry must be aware of fall protection to prevent accidents, as well as citations for infractions. This article discusses fall protection needs and recent research from the testing of personal fall arrest systems (PFASs), which are a common fall protection option for workers on roofs. Finally, the conclusions provide some guidance for post-frame builders on PFAS usage.

THE DANGER OF FALLS IN CONSTRUCTION

Falls from elevation are one of the most common workplace accidents among construction workers. The Bureau of Labor Statistics reported that 34.1% of workplace fatalities for U.S. construction workers during 2010 were a result of falls (U.S. Department of Labor, 2011). Roofers are at especially high risk, being six times more likely than other workers to suffer a fatal occupational injury (Hsiao & Simenov, 2001).

The numbers of fatalities and injuries from falls from height are one reason for the emphasis on fall protection. I have talked to many post-frame contractors and light-frame residential contractors who have expressed a lack of understanding about the fall protection standards. Many statements made by the Occupational Safety and Health Administration (OSHA) can seem confusing, and few if any technical solutions have been provided (Hindman et al., 2013). The need exists for technical solutions to the problem of providing adequate fall protection that satisfy regulations but do not impede, lengthen or add costs to the construction process.

PERSONAL FALL ARREST SYSTEMS

A PFAS is an active system (i.e., connected to the worker), comprised of three parts: an anchorage, a lifeline or lanyard and a body harness. Body harnesses, lifelines and lanyards are standard products used in both residential and commercial construction and are widely available. Body harnesses come in many different styles and price ranges; typically, cheaper harnesses contain fewer features, such as padding. It is very important that the body harness fits the worker correctly. Some of our findings suggest that workers who experience discomfort wearing a body harness are more prone to have difficulty using it and more difficulty using the PFAS overall.

Concerns about the anchorage design on wood structures have arisen. OSHA (n.d.) sets forth these requirements for fall protection systems:

- 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 5,000 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.

According to the definitions given in OSHA 1926.32(m),

- "Qualified" means one who, by possession of a recognized degree, certificate, or professional standing, or who by extensive knowledge, training, and experience, has successfully demonstrated his ability to solve or resolve problems relating to the subject matter, the work, or the project.

In addition, OSHA limits the maximum arresting force that can be applied to an employee:

- 1926.502(d)(16) Personal fall arrest systems, when stopping a fall, shall:
- 1926.502(d)(16)(ii) Limit maximum arresting force on an employee to 1,800 lbs. (8 kN) when used with a body harness.

Commercially available fall arrest anchors are usually rated to support 5,000 pounds or more. Most anchors are made of steel that can carry this force easily. But the question that arises is this: *Can the wood structure that the anchor is attached to carry the load?* At first blush, it appears that the wood structure must carry 5,000 pounds applied to it. Unless the force is applied vertically to cause no eccentric movement of the truss, very few wood structures can support this 5,000-pound load.

The "saving grace" of wood structures is the verbiage in 1926.502(d)(15)(i), which refers to a complete personal fall arrest system with a factor of safety of two. The PFAS is designed for the maximum arresting force (MAF), which must be less than 1,800 pounds. The most effective way to determine the MAF is through testing of the PFAS where the load can be measured. This testing is difficult and requires extensive facilities, but it can be performed in severe cases. In addition to laboratory testing, field tests involving a "dummy drop" can be conducted. Usually, a manikin or other weight of about 200 pounds is dropped. A field drop is said to be successful when the structure does not collapse, the manikin remains suspended, and the manikin does not strike other parts of the structure (e.g., a lower floor).

If testing is not available, another option is to calculate the MAF. In *Introduction to Fall Protection* Ellis (2012) provides a set of equations for calculating the MAF from a vertical fall arrest load or a horizontal lifeline. These equations account for the material of the lifeline, the distance fallen before the PFAS engages (i.e., the rope becomes tight, or a self-retracting lifeline [SRL] stops the descent) and the effect of a shock absorber in the lanyard. A previous article in Frame Building News (Hindman, 2011) discussed the equations from Ellis (2012) in detail. To my knowledge, these equations are the only technical information available to help predict the MAF. Once the MAF has been found from equations, the value should be multiplied by two to comply with the OSHA standards listed above. (Note: Use of these equations is difficult and may not be completely accurate for current materials.)

Assuming the use of an SRL (which reduces free-fall distance to two feet or less), the calculated MAF ranges from 375 to 750 lbs., or 750 to 1,500 lbs. with the safety factor of two. However, the rating of most SRLs is 900 lbs, which is more conservative than the MAF calculated (C. Link, of ITAC Fall Protection Systems, personal communication, 2013). With the safety factor of two, the design load is 1,800 lbs. The choice of an MAF value is made by the qualified person and should include an understanding of the safety equipment as well as any adverse conditions such as weather.

PREVIOUS TESTING OF 2X4 TRUSSES

I have been conducting a research program sponsored by the National Institute of Safety and Health to examine the use of PFASs for light-frame residential construction, particularly trusses composed of 2x4 members. Although these trusses are much lighter than most conventional trusses used in post frame, a short summary of the failures and key results found can apply to post-frame structures as well. The intent of the research is to include testing of post-frame trusses and connections in the future.

A specially designed test fixture was created to load truss roof systems by a horizontal load, called the Horizontal Application of Load Tester **(Figure 1)**. The horizontal load out of plane of the trusses at the beginning of the fall was felt to be the most severe force applied to the trusses, because the trusses are not designed for this force. The HALT has a cable system capable of applying a horizontal load at different heights with a 7,000-pound load capacity and up to 20 inches of travel.

Testing was conducted using a 13-foot span kingpost truss with a 4:12 pitch. Trusses were manufactured at a local truss facility and were composed of No. 2 Southern pine lumber. The 13-foot span is the largest truss size that can currently be tested on the HALT. A set of five trusses was installed using standard hurricane clips with lateral and diagonal bracing.

Figure 1. PFAS anchor used for testing

Figure 2. Testing of kingpost trusses using the HALT

A specialized fall arrest anchor was tested at the center of the five-truss system. This fall anchor had a solid steel shaft two feet in height with a welded ring attachment **(Figure 2)**. This anchor has been successfully used for PFASs in post-frame construction to attach to a single truss member. This testing examined whether the post-frame anchor could be applied to light-frame wood construction.

The lateral bracing of the top chord used three different types of bracing: blocking between trusses, bracing over trusses (simulating short purlins) and an engineered metal brace. All truss systems were loaded at a displacement rate of 15 inches per minute until the trusses failed. Maximum load was recorded from the testing.

The ultimate load of the blocking was 726 pounds, the ultimate load of the wood bracing over the trusses was 752 pounds and the ultimate load of the engineered metal braces was 570 pounds. All three of these bracing schemes have maximum load values less than the 1,800-pound requirement described previously. Figures 3, 4 and 5 are photographs of the truss systems after maximum load was achieved.

In **Figure 3**, the anchor has remained undamaged, yet the peak of the truss where the anchor was attached rotated. This rotation was observed in 2x4 chords but is not expected to be a problem in larger chord members, such as those

Figure 3. Five-truss system with blocking showing bracing pullout near PFAS

Figure 4. Loading of five-truss system with over-the-top bracing and splitting of truss top chord at center

used in post-frame trusses. The greater section size has a larger torsional rigidity that prevents this rotation.

The trusses in **Figure 4** show a tendency to lean to the left, toward the direction from which the load was applied. This was observed in several different tests and helped to develop greater loads when multiple trusses were loaded. The action of the braces on top of the trusses, acting like purlins, helped restrain the center truss from rotating and served to transfer load to the other trusses in the system. Also, note the splitting of the top chord at the brace in the center truss near the middle of the photo.

The trusses in **Figure 5** show a tendency to lean to the left, indicating that the engineered metal braces transferred load between the trusses. However, several braces became detached from the trusses when the teeth of the brace pulled out.

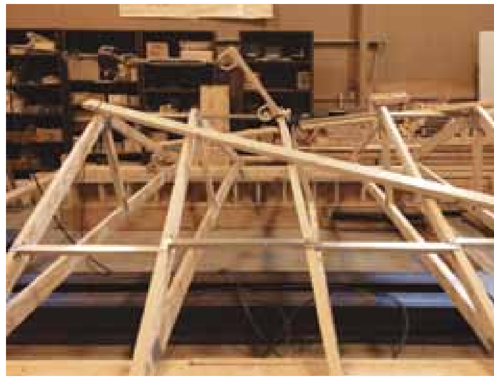

Figure 5. Loading of five-truss system with metal engineered bracing

The PFAS tested was not considered to be a good fit for light-frame 2x4 trusses because of the lower torsional stiffness and smaller sizes of the trusses. Residential trusses need to rely on the combined capacity of several trusses to support a fall arrest anchor. An alternative that can produce test values of 1,800 pounds or more is to increase the frequency and placement of cross-bracing within the truss system. This additional bracing aids in the transfer of forces between the trusses, allowing the truss system to support greater loads.

CONCLUSIONS AND RECOMMENDATIONS FOR POST-FRAME CONSTRUCTION

The information in this article is meant as an explanation of recent testing that can help in the design of PFASs for post-frame construction. It is important that all PFASs are designed by a qualified person, defined as a person knowledgeable about safety procedures with job site authority to enforce those procedures. Consultation with safety professionals or OSHA is highly recommended. In particular, OSHA's On-site Consultation website (www.osha.gov/dcsp/smallbusiness/consult.html) is focused on providing information to help small businesses become compliant. Other authors have reported that consultation with OSHA offices was helpful for deciding upon the use of proper fall arrest devices and methods (Kaskutas and Hunsberger, 2013). Be sure to consult manufacturers' product literature or support to understand the safety equipment you are using. On the basis of testing and experience,

HOW CAN BUILDERS ENSURE THAT THEIR FALL ARREST SYSTEM IS ADEQUATE?

- Contact the OSHA Onsite Consultation office. A proactive approach to safety is appreciated, and you may get some useful advice.
- Hire a safety consultant to review your current PFAS.
- Conduct a dummy drop of your own, supervised by a qualified person. Be sure to record it, and invite workers to witness the test.
- Communicate your desire for a safe workplace to all employees and subcontractors. Research has found that a positive attitude toward safety by management affects employees' attitudes toward safety.

the following advice is offered:

- The most important conclusion from truss testing is that the wooden structure a PFAS anchor is attached to *must be able* to carry the MAF load. Any structure to which an anchor point is attached should be inspected. Connections at the truss-heel joint are particularly important and should be fully constructed before trusses can be loaded.
- The increase in the MAF compared to a construction worker's weight (200 pounds) is *not* meant to protect the structure or ensure that the structure remains undamaged. As a person falls, the amount of force generated increases. The MAF values measured in testing occurred when the truss peaks deflected up to 10 inches in the horizontal. The structure must maintain enough structural integrity to prevent collapse due to a fall load.
- Qualified persons should conduct a "stack-up" of the particular safety equipment used before installing. A stack-up is a listing of the lengths of all the safety equipment, as well as estimates on the stretch of lifelines and the additional length when shock absorbers deploy. Compare this height to the location of the PFAS anchor on the structure. Be aware of the presence of intermediate stories or work platforms that could shorten or interfere with this height. Information on particular safety components is available from the manufacturers of the safety products.
- Although the design of a PFAS is important, builders should also have a rescue plan in the event of a fall. Workers who fall and are restrained by a PFAS must be rescued, and the workers rescuing them must comply with all OSHA safety provisions. Workers who fall and are restrained need medical attention to check for injuries, including the development of blood clots due to suspension in the harness.
- After a fall has taken place, the truss system should be inspected for damage. Typical damage observed in the light-frame construction testing included rotation of truss plates, rotation of the truss-heel connection, withdrawal of bracing nails, and splitting of truss chords. Trusses that are involved in a fall should be replaced, or appropriate repairs must be authorized by a registered design professional. In addition, any PFAS equipment involved in a fall should be inspected by a qualified person before being returned to service.
- Anyone who has worn a body harness knows that some discomfort is to be expected. It is important to take the time to adjust a body harness for a specific person. The level of discomfort with a body harness can be a distraction and negatively affect worker attitudes about the entire personal fall arrest system.
- Work to increase the safety climate of your job site. The intent of fall protection is to have workers be safe and able to go home after work. Explain the intent of the fall protection rules to your crews. If possible, take helpful suggestions about the PFAS into consideration.

ACKNOWLEDGMENTS

This work was supported by an award (5R01 OH009656) from the Centers for Disease Control and Prevention (CDC). Its contents are solely the responsibility of the author and do not necessarily represent the official views of the CDC. The author would also like to acknowledge Tony Smith-Jackson, co-investigator, and Justin Morris, Lori Koch, Milad Mohamadzadeh, and Joe Angles, graduate assistants who have worked on the project.

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