Safety should remain top concern

Technical requirements for fall protection systems

By Daniel Hindman, PhD

Workplace accidents such as falls are a source of great concern. The Occupational Safety and Health Administration recently increased its levels of job site surveillance and fines. As workers and companies are pushed toward higher levels of productivity, awareness of the expense and loss associated with workplace accidents is increasing.

Accidents are being viewed as unnecessary project expenses. Accidents result in severe physical and mental harm to workers, resulting in direct costs (hospital bills and time off work), indirect costs (workers' compensation and insurance rates), and lost time (time associated with the affected worker, the crew coping with the accident scene and time to train new crew members).

One source estimates the average direct cost of a workplace accident at approximately $17,000 (Lipscomb, Li, & Dement, 2003). This estimate does not include additional costs of falls such as negative press and loss of reputation in the community and industry.

Discussions about safety in this publication usually focus on current OSHA regulations or litigation after accidents have occurred. This article focuses on preventing and eliminating hazards and situations that can lead to falls. Falls often are deadlier than other accidents and have been associated with higher costs than other accidents (Lipscomb, Dement, & Behlman, 2003). I wrote an article for *Frame Building News* in November 2008 titled "Safety Trends Affecting the Industry;" the article discussed falls from heights and fall prevention concepts. This article will expand on ideas previously discussed, including the role of design and construction management in maintaining a safe workplace and the design and use of personal fall arrest systems (PFAS). This article also features recent research awarded by the National Institute of Occupational Safety and Health at Virginia Tech in Blacksburg, Va.

Falls in construction

Falls are one of the most prevalent accident types among construction workers. Some safety experts have gone so far as to label the problem of falls as epidemic. According to a Bureau of Labor Statistics survey of occupational fatalities in 2007, 15 percent of all workplace fatalities were caused by falls (BLS, 2010). Between 1992 and 2007, the annual number of workplace falls reported by the BLS varied between 600 to 847 falls per year, with an overall increase in the number of falls annually (BLS). When examining fatalities for construction workers in 2007, 37.1 percent of all fatalities were the result of falls (BLS). Falls are the second-highest source of workplace fatalities and the greatest single source of fatalities in construction.

Fall protection systems

A variety of fall protection tools are available for workers. Fall protection systems for construction are regulated by OSHA 29 CFR 1926 (OSHA, 2010). This standard applies to all commercial construction, and, due to recent changes, soon will apply to all residential construction. Section 1926.502(d) describes PFAS. A PFAS is an active system (i.e., connected to the worker) that prevents injury in the event of a fall. A PFAS consists of three parts: anchorage, lifeline or lanyard and harness. Specific guidelines are provided for each component of the PFAS. The use of full-body harnesses is common in the construction industry and the harnesses have become standard jobsite tools. Anchorage and lifeline system requirements are discussed below.

Anchorages

The discussion surrounding PFAS anchorages can be confusing. Some safety-related sources (Ellis, 2001) discuss safety for a variety of industries and provide several different values for anchorage strength. For clarity, the exact wording from OSHA 29 CFR 1926.502 is presented below:

- 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 pounds (22.2kN) 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.

There is little knowledge regarding what comprises engineering design and the exact value that should be assigned a safety factor of two. Several sources do not include this second provision in their discussion. Many researchers have commented that it is difficult to achieve anchorage on wood roofs, especially steep-sloped roofs. No information was found to help alleviate this situation. There is no discussion on the direction of loading, type of loading or other factors. It is interesting to note the detail included in ASTM material testing standards for all materials (structural or otherwise) contrasts to the vague statements above that directly relate to worker safety. If safety is as important as everyone claims it is, shouldn't there be clear, established guidelines and procedures to evaluate alternative systems?

Lifelines and lanyards

All lifelines and lanyards must have a minimum breaking strength of 5,000 pounds, while self-retracting lifelines may have a minimum tensile load of 3,000 pounds in some cases. An employee must not freefall more than 6 feet or contact a lower level. The maximum deceleration distance is limited to 3.5 feet. The most important value in lifeline or lanyard design is the maximum force applied to an employee during a fall must be restricted to 1,800 or fewer pounds. Ellis (2001) discussed the calculation of the maximum force placed upon an employee falling. The force is a function of the weight of the worker, the stiffness of the rope, and the type of fall arrester and shock absorber used. **Table 1 and Table 2** provide values for a and s, respectively, for different devices.

$$F = \left(0.031\,W\,g + 1.012\sqrt{0.003125\,W\,f\,K}\right)\frac{a\,b\,s}{c}$$

where,

F = maximum arresting force, lbs
W = weight of employee, lbs
g = acceleration of gravity, 32.2, ft/sec^2
h = free fall distance,6 ft
L = lanyard/lifeline length, ft
f = fall factor (h/L) ratio
K = lanyard tension modulus, psi
a = arrest device reduction factor, Table 1
b = body support reduction factor, 0.8 for body harness
c = rigid weight/manikin factor, 1.4
s = shock-absorber reduction factor, Table 2

Table 1: Fall Arrest Device Reduction Factor, a	
Inertia Type, Wire Rope Lifeline	0.7
Inertia Type, Synthetic Lifeline	0.9
Friction	0.7
Mechanical Level	1.0
No fall arrester	1.0

Table 2: Shock-Absorber Reduction Factor, s	
Tear Stitches	0.6
Tear Fabric (Synthetic)	0.7
Tear Fabric (Wire Rope)	0.6
No Shock Absorber	1.0

For example, a 250-pound worker connected to a 6-foot lanyard with a wire rope (K = 13,000,000 psi) with no fall arrester and no shock absorber creates a force of 1,990 pounds, which is more than the OSHA-recommended force of 1,800 pounds. To decrease the force, a fall arrester (an inertia-type, wire rope lifeline that produces a force of 1,390 pounds) or a shock absorber (tear stitches that produce a force of 1,190 pounds) can be used. Changes in type and stiffness of the rope used also change the force values. Do not overlook lanyard and shock absorber choices when designing PFAS.

Construction site safety and prevention through design

In 1989 the American Society of Civil Engineers developed Policy 350, titled Construction Site Safety. The rationale for this policy was to encourage government and regulatory groups to "emphasize and apply an approach in which cooperation, education and training is the primary focus" (ASCE, 1989). **Table 3** details the policy's recommended responsibilities. The idea that safety should be a responsibility of all parties involved in construction is not yet a universal concept in the industry, however, especially among design professionals.

I introduced the concept of prevention through design (PtD) in a previous *Frame Building News* article. As the name implies, this concept discusses the role of structure design in creating safer working conditions for the construction, maintenance and operation of a building. The idea of "constructability" — meaning the choice of materials/methods to reduce worker time and error (increasing the thickness of a shearwall panel before decreasing nail spacing to gain more strength) — has been considered, but not with a specific emphasis on safety. PtD was

Table 3. *ASCE Policy Statement 350: Construction Site Safety Responsibility of Personnel*

ASCE Policy Statement 350: Construction Site Safety Responsibility of Personnel

Personnel	Responsibility
Owners	Assigning overall project safety responsibility and authority to a specific organization or individual, (or specifically retaining that responsibility);
Design Engineers	Recognizing that safety and constructability are important considerations when preparing plans and specifications
Contractors	Maintain safety of their employees and of all other persons in the work area or on the worksite

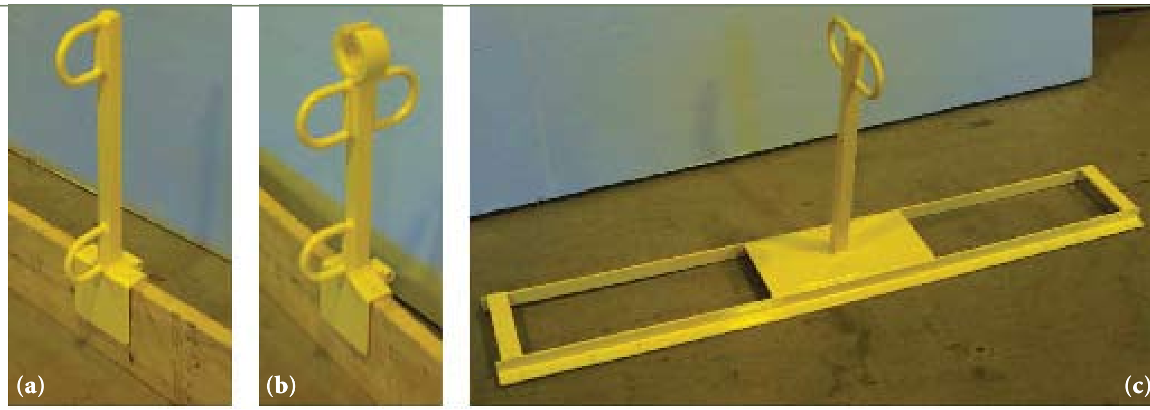

Figure 1. Personal fall arrest system used for post-frame construction: **(a)** eave-mount bracket, **(b)** ridge-mount bracket, **(c)** roof-mount-over-sheathing bracket.

made popular by John Gambetese, PhD, a professor at Oregon State University. The concept has been accepted at NIOSH, which is the construction safety research division under the National Institutes of Health. NIOSH is considered a sister organization to OSHA, which conducts regulatory activities. The National Occupational Research Agenda (http://www.cdc.gov/niosh/nora/), a roadmap document created by NIOSH to guide research efforts, has a heavy emphasis on PtD concepts. Gambetese and other researchers have worked to create a Design for Construction Safety Toolbox of PtD-specific skills for various types of construction.

A PtD idea that has been incorporated into post-frame construction for fall protection is the installation of permanent D-ring anchors at the ridge of a roof. Some post-frame companies already use these devices. The D-rings are connected to the truss top chords by rows of nails. The D-rings protrude under the ridge cap and can be accessed for roof maintenance and repair and during construction. This simple and inexpensive addition to the project creates a safer environment during construction and afterward.

Current Research at Virginia Tech

Recently, Drs. Daniel Hindman and Tonya Smith-Jackson were awarded a NIOSH grant to study the use of personal fall arrest systems in construction. The focus of this project was to develop a PFAS for residential construction, given the exemptions from fall arrest equipment that have been in place for a number of years. The idea for this project has its roots in post frame. When I attended the 2008 Frame Building Expo, I saw a presentation that was hosted by several post-frame companies (including Wick Buildings, Brickl Brothers, FBi, and Finger Lakes Construction) on the PFAS systems they used. I was intrigued with the system that Wick Building and Brickl Brothers used.

Figure 1 shows the three components of their system. The first two elements shown (a and b) are attached to the end truss on the ground with ropes between the brackets. The end truss is lifted into place and the PFAS is in place as soon as roofers access the trusses. For the truss-setting portion of construction, workers continue setting roof and eave brackets at intervals along the length. When the sheathing is placed on the roof, the roof mount bracket (c) is used. From talking with the companies involved, the safety system seemed to have minimal effect upon the workers' tasks.

Smith-Jackson, from the industrial systems and engineering department at Virginia Tech, specializes in understanding workers' attitudes and actions. One of the problems encountered when conducting safety research is the ability to understand the ways in which safety equipment and tools are used. Successful safety programs need to influence workers to change their attitudes and behaviors and use safety equipment. Some safety literature discusses a "safety climate" measure, which is a measure of attitudes and impressions that workers have towards their employer, jobsite and peers.

In general, a better safety attitude results in a safer jobsite. There is no way to control for random accidents on a jobsite, so the safety climate can only provide trends and mostly is used as a research measure.

The purpose of the Virginia Tech research is to explore the potential integration of post-frame construction fall-arrest systems into residential construction, given its seemingly more usable design. **Figure 2** provides a general outline of the tasks involved in this research. Three main objectives were identified. The first objective is to determine the baseline safety climate and usability studies for both residential construction workers and post-frame construction workers. These questionnaires serve as the basis to identify if post-frame workers have different attitudes towards using PFAS compared to residential construction workers. The second objective is the testing and redesign of the brackets shown in Figure 1 for use in residential construction. While the current system seems fitted for roofs, there are no provisions for second-story work, for which it would be preferable to have a central mast or tower exceeding the height of the workers. The second objective is to test the strength of the post-frame system, and, based on these measures, develop a residential fall arrest system (RFAS), which also will be tested. As part of the redesign for the second objective, some "scaled-world" testing will be conducted; a floor section will be constructed in the laboratory and workers will assemble the RFAS. In the third objective, the new RFAS will be field tested to determine the system's usability. Field observations will be combined with surveys to help improve the final RFAS product.

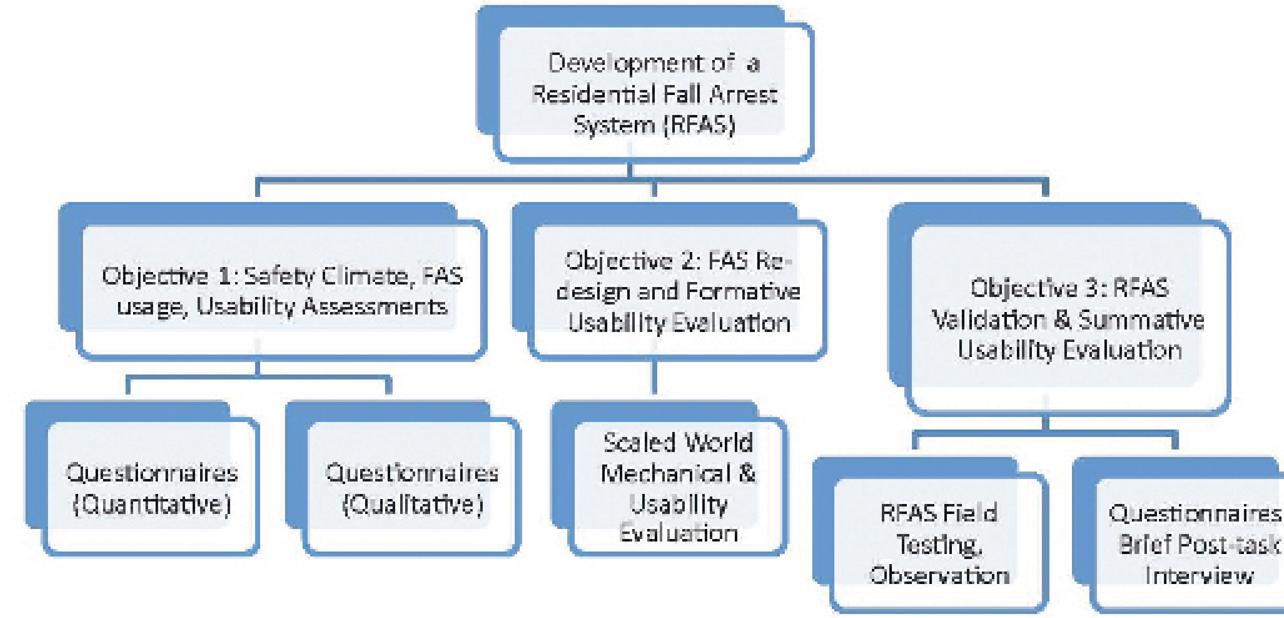

Figure 2. Schematic design of a research program to develop a residential fall arrest system.

Although the final output of this project will be a PFAS designed for residential use, we also hope to understand the qualities of a safe working environment and the ways in which the design and regulatory communities can take advantage of these qualities to help increase worker safety. The project approach is novel in several ways and incorporates Hindman's expertise in falls, mechanical testing and the design with human factors, usability design and field testing experience of Smith-Jackson. The link between mechanical testing and worker attitudes as equal components in the use of safety equipment is unique. Our study area includes post-frame and residential contractors in Virginia, West Virginia and North Carolina. If you are interested in participating, contact Hindman at dhindman@vt.edu or 540.231.9442.

Conclusions

Construction site accidents are a serious matter resulting in lost time, injuries, expenses and loss of reputation. Workers are required to use PFAS or other safety equipment required by OSHA 1926.502. An anchorage must have a force of 5,000 pounds or an engineered system must be capable of carrying twice the rated load. The use of engineered systems needs to be clarified to expand the use of safety systems. Lifeline forces should be calculated, and methods to do so were presented in this article. All members of construction companies (owners, designers and contractors) play a role in jobsite safety. PtD concepts can be used in the design of a structure to reduce safety issues. Current research is being conducted at Virginia Tech to study the capacity of fall arrest systems for post frame and other wood buildings.

References

American Society of Civil Engineers. (1989). Policy statement 350: Construction site safety. Retrieved December 2, 2010, from http://www.asce.org/Content.aspx?id=8544.

Bureau of Labor Statistics. (2010). Census of fatal occupational injuries (CFOI)—Current and revised data. Retrieved December 2, 2010, from http://www.bls.gov/iif/oshcfoi1.htm.

Ellis, J. N. (2001). Introduction to fall protection (3rd ed.). Des Plaines, IL: American Society of Safety Engineers.

Lipscomb, H. J., Dement, J. M., & Behlman, R. (2003). Direct costs and patterns of injuries among residential carpenters, 1995–2000. Journal of Occupational and Environmental Medicine, 45(8), 875–880.

Lipscomb, H. J., Li, L., & Dement, J. M. (2003). Falls among union carpenters. American Journal of Industrial Medicine, 44(2),148–156.

Occupational Safety and Health Administration. (2010). 29 CFR 1926 subpart M safety and health regulations for construction: Fall protection: Fall protection systems criteria and practices. Retrieved December 2, 2010, from http://63.234.227.130/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=10758.