

Wood Design
FOCUS

A JOURNAL OF
CONTEMPORARY
WOOD ENGINEERING

Volume 23, Number 1

Spring 2013

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Editorial

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. 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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Published by the
Forest Products Society

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Wood Design Focus
(ISSN 1066-5757)
is published quarterly by:
Forest Products Society
2801 Marshall Court
Madison, WI 53705-2295
Telephone: (608) 231-1361
Fax: (608) 231-2152
www.forestprod.org

The annual subscription rate is \$45USD to subscribers who are Forest Products Society members and \$60USD to non-members and \$125USD for institutions and libraries. The Forest Products Society and its agents are not responsible for the views expressed by the authors. Individual readers of this journal, and non-profit libraries acting for them, are permitted to make fair use of the material in it, such as copying an article for use in teaching or research. Permission is granted to quote from this journal with the customary acknowledgement of the source.

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Preventing Falls in Construction: A Collaborative Effort to Launch a National Campaign

Christine M. Branche, Ph.D.

Falls kill.

They are a persistent hazard found in all occupational settings. And, they are the leading cause of construction deaths, accounting for one-third of on-the-job injury deaths in the industry. Each year in the United States, more than 200 construction workers are killed and over 10,000 are seriously injured by falls. Injuries and fatalities from falls represent a major and preventable public health problem. For occupational falls, construction workers face disproportionate risks. Construction—building new structures, renovating and altering existing ones, maintaining and repairing others—whether they are houses, roads, or workplaces, requires both skilled workers and responsible employers. In 2010, there were 9.1 million construction workers (including self-employed workers) in the United States, accounting for 7% of the national workforce (1). Of the 4,547 U.S. workers who died on the job that year, however, 17% (n=780, including both public and private sectors) were construction workers—more than any other single industry sector and nearly one out of every five work-related deaths (2)¹. The number of fatal injuries in construction increased about 35% from 1992 to 2006, and then dropped 40% by 2010, reflecting fluctuations in the overall construction employment trend during this time period (4,5). Construction is a large, dynamic, and complex industry sector valued at around \$807.1 billion (6). Construction worksites are organizationally complex multi-employer sites and present numerous health and safety challenges.

Circumstances associated with falls at construction worksites frequently involve slippery, cluttered, or unstable walking/working surfaces; unprotected edges; floor holes and wall openings. The leading fatal events in con-

struction, however, are falls related to work on roofs, ladders and scaffolds. Combined, these three account for roughly two-thirds of all fatal falls in construction (n=1806 falls during 2003-2009) (4). They represent very different problems, however. In roofing jobs, the key issue is failure to use fall prevention equipment and best practices. For ladders, problems occur when using the wrong type of ladder, using defective ladders, or not using the ladder correctly. Hazards with scaffolds occur when they are assembled incorrectly (e.g., not fully planked, or not level), or during assembly and dismantling. For each of these, improvements in design could reduce hazards. In roofing for example, designs that reduce fall hazards and accommodate the placement of fall protection equipment would be key improvements. Pre-job planning and designs that allow for the installation of stairways earlier in construction process would help to reduce ladder hazards. Better designs and improved pre-job planning could also reduce fall risks associated with unprotected edges, floor holes and wall openings in the construction process and the finished project.

Federal regulations and industry consensus standards provide specific measures and performance-based recommendations for fall prevention and protection. Unsafe practices and low safety culture and climate, nevertheless, persist in construction. Falls in construction that are related to serious violations of Occupational Safety and Health (OSHA) standards are among the most frequently cited violations (7). Fall injuries constitute a considerable financial burden: workers' compensation and medical costs associated with occupational fall incidents have been estimated at approximately \$70 billion annually in the United States (8). Regulations and practices need to improve, but so too must the designs of the edifices themselves. It would be imprudent to suggest otherwise.

Conventional regulation, enforcement and consultation

¹Preliminary data from OSHA for 2011 notes that there were 4,114 U.S. worker fatalities in private industry, of which 721

efforts have been the primary mechanisms used to increase the use of fall prevention by employers. Additional efforts over the years have attempted to use media and other communication tools to provide data on the nature of the falls problem in construction. Falls have continued despite all of these efforts. A successful reduction of fall injury and fatality rates requires the continued concerted efforts of regulators, industry leaders, professional associations, labor organizations, employers, employees, safety professionals and researchers in improving the work environment, implementing effective fall prevention and protection technologies, educating continuously the workforce, and improving the work safety culture. And a single, simple effort to urge the provision (employers) and use (workers) of falls prevention equipment and other strategies is essential. Is there a role for design, and for architects and designers? Absolutely. In fact, designs that remove intrinsic hazards are the best solution.

The National Institute for Occupational Safety and Health (NIOSH) helps to organize stakeholders through its stewardship role through the National Occupational Research Agenda (NORA). A NORA Construction Sector Council was formed to discuss leading priorities in construction safety and health research and practice, and to create national efforts to address them. Through this government-labor-industry partnership, NIOSH engages a number of construction sector stakeholders representing state and federal government agencies, professional organizations, trade associations, labor organizations and private industry to develop and address a list of leading construction research issues within the United States. A key goal among these research topics was formulating social marketing campaign that could simultaneously be based on research, effectively increase safety awareness, and influence work safety behavior to reduce fatal and non-fatal falls from heights.

The NORA Construction Sector Council examined existing campaigns, as well as critical background information, and collected and compiled data, with the aim of duplicating and expanding an effective campaign, if one could be found. After an exhaustive review of more than 30 published and unpublished materials, including articles in peer-reviewed scientific journals, newspapers, magazines, online sources, campaigns, and reports covering the period January 2006 through July 2011, NIOSH and its partners determined that designing a new social marketing campaign would be the best course.

A pilot effort was organized and implemented through focus groups that included construction contractors, on-site supervisors and workers, to address and reduce falls,

fall-related injuries and fall-related fatalities among construction workers. Using outcomes from the focus groups, a social marketing campaign was designed, integrating findings from falls prevention research, and effective falls prevention practices. Partners worked together to coordinate printing, publishing, internet and other electronic functions. Based on the evidence, the primary target audience is small residential construction contractors. Supervisors and foremen on job site, and the construction workers themselves, including Spanish-speakers, make up the secondary and tertiary target audiences, respectively. On Workers' Memorial Day, April 28, 2012, a two-year national information and media campaign on falls prevention in construction was launched officially nationally through the this partnership (<http://www.stopconstructionfalls.com>).

The campaign encourages everyone in the construction industry to work safely and use the right equipment to reduce falls, but there is special emphasis on residential construction. The goal of this national campaign is to prevent fatal falls from roofs, ladders, and scaffolds by encouraging residential construction contractors to plan ahead to get the job done safely; provide the right equipment; and train everyone to use the equipment safely. The campaign has the capacity to report outcomes, and builds in evaluation components. A variety of campaign materials are available to raise awareness about construction falls, and to provide practical information about fall prevention. These include posters, fact sheets, training materials, stickers, and more. New materials have been and will continue to be released on a regular basis over the course of the campaign.

Broad engagement and promotion across the United States has been encouraged, including by state agencies and public health practitioners. The response to the campaign has been enthusiastic and supportive. As of October 2012, over 300,000 people received information about the campaign through the Occupational Safety and Health Administration (OSHA) alone; over 6,000 fact sheets have been distributed in English and Spanish each; and more than 12,000 page views over a two-month period were documented among the websites supporting the campaign. Broadly, home builders, contractors and their site supervisors, labor, professional associations, state and federal government agencies, and academics have supported and endorsed the campaign. In an evaluation conducted four months after the campaign was launched, audience response and other components were assessed.

Despite the early success of the campaign, challenges

remain. Most of the dissemination efforts have been to organizations that are national in scope. Key target audiences in residential construction usually work in small scale operations. Redoubling efforts to encourage distribution to small contractors, however, will be critical to the overall success of the campaign. Reliance on partners and stakeholders to disseminate campaign materials and messages has been the central method by which to maintain partner and stakeholder engagement, to decrease costs, and to increase efficiency. It has been a challenge, however, to encourage dissemination to contractors and others in management (the primary target audience), and not to the workers themselves. Addressing these and other challenges will frame efforts 2013.

It is clear that developing relationships with engineers and architects is critical. Prevention can often best be accomplished through designs that reduce or eliminate hazards (Prevention through Design; <http://www.cdc.gov/niosh/topics/PtD/>). Even with its focus residential construction, the fall prevention campaign messages apply to iron work, wind power turbine and telecommunications tower erection and maintenance, other construction, and any work at heights. NIOSH and its stakeholders welcome the opportunity to work more closely with architects, engineers and related professionals on this topic.

Injuries and deaths at work are a significant public health problem. Injuries and fatalities in construction take a large toll on its workforce, and the impact extends beyond the workplace to encompass workers' families and communities. Preventing fall-related injuries in construction requires the consistent and concerted efforts of multiple parties using multiple strategies. The new prevention campaign is one such strategy. Others will be needed, and working with professionals who bring a different perspective will be important as the field moves forward.

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Residential Fall Protection Case Study — Habitat for Humanity St. Louis

Vicki Kaskutas, MHS OTD, Kyle Hunsberger

Abstract

Residential construction builders and contractors must quickly comply with OSHA's new fall protection requirements for residential construction. This paper describes the change process, fall protection equipment, and building methods a charitable home building organization to comply with these new requirements. Reliance on a volunteer workforce poses unique challenges; however the many solutions described in this paper are also applicable to commercial residential builders. This organization used creative problem-solving, collaborated with local professionals and equipment suppliers, and consulted regularly with OSHA compliance representatives to overcome the many obstacles encountered when transitioning to the use of conventional fall protection during new home construction.

Introduction

Falls from height remain the most common cause of workplace fatalities among all construction workers, accounting for the highest number of worker deaths in residential construction and framing (Bureau of Labor Statistics, 2011). As a result, OSHA rescinded its *Plain Language Interim Fall Protection Compliance Guidelines for Residential Construction* (STD 03-11-001), which outlined fall prevention procedures that could be used instead of conventional fall protection while performing certain residential construction activities. OSHA's reasoning for rescinding the Guidelines was that "feasibility is no longer an issue" (OSHA, 2010) due to "advances in the types and capability of commercially available fall protection equipment" (OSHA, 2010). Since June 16, 2011, procedures described in 29 CFR 1926.501 (OSHA, 2006) must be followed when performing residential construction. OSHA prepared a *Guidance Document for Residential Construction* (OSHA, 2011) that outlines work methods and equipment to provide conventional fall protection during each stage of residential construction. OSHA contin-

ues to provide on-site consultation, compliance assistance, resources, and training. A nationwide outreach campaign to raise awareness about the fall hazards at construction sites and to provide educational resources and training tools was launched in April 2012 through a government-labor-management partnership of federal and state government, private industry, trade associations, academia, and professional and labor organizations (<http://stopconstructionfalls.com/>).

Despite over 1,000 training sessions and 1,200 outreach activities by OSHA representatives, (OSHA, December 11, 2012), residential builders continue to struggle to determine the most suitable fall protection methods and equipment for their application and context. OSHA's Guidance Document is a valuable resource; however its generic nature does not provide users with specific information about the fall prevention equipment demonstrated in the document, such as the device name, manufacturer, and basic use and installation requirements. Many small residential builders do not have the time and resources to readily translate and apply the information provided in OSHA's Guidance Document, especially in the current market which is slowly recovering from a 75% drop in new home starts in the past six years (National Association of Home Builders, 2012). As a result, builders have purchased devices that do not match their needs and contexts, only to retire them to the storage trailer and continue to work without required fall prevention measures.

This paper describes one charitable organization's experience transitioning to OSHA's new fall prevention requirements. This organization builds homes with a volunteer staff that is taught and directed by on-site carpentry professionals. Most volunteers lack construction knowledge, skills of the carpentry trade, training in personal fall arrest systems, and the agility of seasoned construction professionals; therefore this organization had to

deal with challenges that traditional builders would not encounter. The homes built by this organization are usually smaller and less intricate than custom homes built by commercial builders; however they are similar to the small tract homes built in some new home developments. Despite these differences, much can be learned from this builder's experiences and solutions, which will be presented by phases of the home construction process.

Methods

We present a case study of the experiences and practices of a single home builder. Unstructured telephone interviews and in-person discussions with the building director of St. Louis Habitat (DH) for Humanity, and naturalistic observation at five building sites were used to gather details about fall protection practices. Photographs of the equipment and processes were taken during the site visits. The building director co-authored this report to ensure accuracy. This work occurred as part of a research study to improve use of fall protection technologies in residential home builders, and has been reported as a case study for the national fall prevention awareness campaign.

Results

In order to fully understand the new fall protection requirements, the building director for the St. Louis Habitat for Humanity reviewed OSHA's Construction Standards (CFR 1926.501) in detail and carpentry professionals that work for him attended a formal OSHA informational session. Next, they performed an extensive internet search to learn about the equipment pictured in OSHA's Guidance Document, including identifying manufacturers, reviewing manufacturer's installation instructions, and locating local vendors (personal communication, Kyle Hunsberger, June 6, 2012). They collaborated with a rental equipment company who was familiar with fall protection equipment, and an engineering firm, machine shop, and overhead crane company. He and his staff called OSHA's compliance hotline many times with questions, which were always answered by an OSHA representative. The building director spent approximately 40 hours determining the fall prevention technologies and methods that were best suited for the types of homes that they construct. The director noted that they talked through many possible scenarios and identified solutions for each; stating, "we had to learn how to build the homes all over again". He reported they have standardized the building process around fall protection and incorporated fall protection "into our culture". Fall protection methods used at Habitat for Humanity St. Louis are described in detail for each stage of home construction.

Installation of first-floor joists

After the basement foundation is poured, the over-dig area is filled in half-way with dirt, leaving approximately 39" of the foundation exposed. This allows the workers to stand in this area to set the first-floor joists, with the foundation wall acting as a guardrail of appropriate height to prevent the workers from falling into the basement. After the floor joists are set and fall protection is installed, the over-dig area is filled in completely. This method requires use of heavy equipment twice to fill the over-dig area. Since Habitat for Humanity commonly builds several homes in the same location, this is feasible; it may also be feasible for builders who have several builds in a subdivision.

Installation of first-floor sheathing

After the floor joists are installed, a safety net is installed over the home's basement. Habitat for Humanity sets the floor joists on 2' centers, so there is a risk of falling between the joists (Figure 1). They purchased several sizes of nets to match the sizes of homes that they build. Since the commercially-available bracket to attach the nets was not designed for residential applications, they had a special L-shaped bracket designed and fabricated by a machine shop (Figure 2). These brackets are hooked to a 2"x4" board for ease of placement. After the brackets are in



Figure 1. Net Under Floor Joists on 2 Foot Centers

place and the net is inspected, it is stretched snugly into place (Figure 3). Installation takes 15-20 minutes. As the net can stretch during the workday, it is inspected regularly and re-stretched as necessary. At the end of the workday, the net is loosened to allow it to return to a normal resting length. In order to protect the nets from damage when not in use, they are stored in large rubber tubs (Figure 4).

First-floor wall setting

Since first floor walls can be raised from the ground level and most homes are on level lots, there is no need for fall protection during this construction stage. In order to prevent workers from having to use a ladder to install the house wrap/sheathing, this is installed prior to raising the wall.

Installation of second-floor joists and floor sheathing

A combination of wall hanging scaffolds and safety nets are used to protect workers installing second-floor rafters and floor sheathing. The building director worked with a local equipment rental company to identify various types of hanging scaffold systems. Habitat for Humanity purchased the hanging scaffold brackets, but they rent the walk boards from the equipment supply company, as

storage space and manpower to maintain the boards are limited. Before the first-floor walls are raised, the brackets for the hanging scaffold are attached to the exterior walls. The wall sheathing is notched to allow for the scaffold brackets to be installed (Figure 5). The hanging bracket system used requires interior bracing to support the weight of individuals on the scaffold, so these braces are installed immediately (Figure 6). The scaffold walk boards are installed from ladders. Three guardrails are installed on the hanging scaffold to provide a barrier tall enough to protect workers who are installing floor sheathing and second-floor walls (Figure 7). A safety net is installed over the top plate of the first-floor walls to protect workers from falling into the home while installing rafters and floor sheathing. A bin was fabricated on top of a skid to store the scaffolding and transport it to and from the work site (Figure 8).

Second-floor wall setting

Workers setting the walls from the floor sheathing are protected from a fall over the edge by the guardrail of the hanging scaffold guardrail system. The guardrails are reused on multiple home builds.



Figure 2. Net Bracket to Hook to Wall



Figure 3. Net Pulled Snugly in Place



Figure 4. Bin to Store Nets after Use

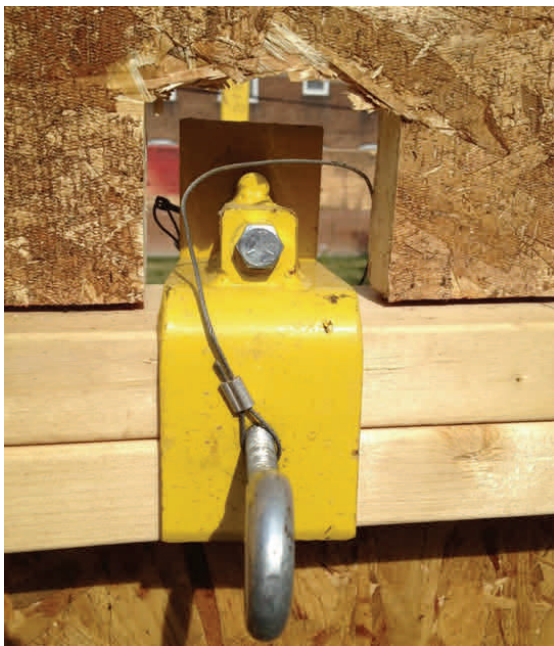


Figure 5. Notching of Wall for the Scaffold Bracket

Stair openings

Pre-built stair-covers are positioned into place over the stair openings, usually 2-3 per stair opening (Figure 9). These have openings cut into the top to slip the hand into to remove; however these openings should have removable covers as they are over 2" in diameter (note that these are missing on Figure 9). After the stairs are built, the stair-covers are lifted to allow access to the lower level prior to guardrail fabrication. Using 2-3 sections of stair-covers ensures that they are light enough to be handled by one worker, possibly two. In 2-story



Figure 6. Bracing Required for the Scaffold System

homes, after the first floor stair opening is railed, the stair cover is moved to the second-floor stair opening (Figure 10). The stair-covers are re-used on multiple home builds.

Roof truss setting, roof sheathing and shingling, and soffit installation

The entire roof assembly is built on the ground next to the house and lifted into place by a large overhead crane. A stationary base is built first, and the roof trusses are set onto this base (Figure 11). Guardrails on the end trusses protect workers constructing the roof assembly from falls over the gable ends (Figure 12). A large wood-beam is built into the center of the roof system to support the weight of the roof when lifted into place by a crane; this beam is permanent. An engineer determined the beam's size and the bracing needed to support the beam and lift the roof assembly. This engineer volunteered his services and consulted with the crane company to ensure that the correct spreader bar was used to lift the roof assembly. Roof sheathing and shingling is installed while the roof assembly is on the ground, as are the soffits, plumbing stacks and flashing. Two permanent roof anchors are attached to the top of the shingled roof. Two small openings in the roof are left unshathed to allow the crane to access the beam. The crane company uses a spreader bar that is the size specified by the engineer to handle the weight and size of the roof assembly. If the crane must make a long lift, a



Figure 7: Three Rows of Guardrail on Hanging Scaffold



Figure 9: Stair Opening Covers Sections



Figure 8: Storage Bin for Hanging Scaffold



Figure 10: Stair Opening Covers from Lower Level



Figure 11: Stationary Base for Roof Assembly

larger crane is required (120 ton). Workers stand on ladders inside of the home to guide the roof assembly into place and to fasten it down. After the roof assembly is secured, a trained carpenter anchors wearing a body harness attaches a lanyard to the roof anchors to sheath and shingle the small openings in the roof. The roof anchors are left in place for use during future maintenance operations.

Installation of siding

On most one-story homes, siding can be installed from ladder jacks. If the height exceeds 12', they set up mason scaffolding as they determined it to be safer than other types of scaffolding systems. In urban sites, they occasionally use snorkel lift, scissor lift or boom devices.

Discussion

This case study can help residential builders transition their building practices to become compliant with OSHA's revised fall protection standards. The St. Louis Habitat for Humanity used a logical approach to problem-solve fall protection for each phase of the construction process. After understanding what OSHA's recent actions meant, the next step was to understand OSHA's requirements for the three types of conventional fall protection described in CFR 1926.501 - specifically, guardrails, safety nets, and personal fall arrest systems (PFAS). Habitat for Humanity chose to use guardrails and safety nets to protect their volunteers instead of PFAS; however these had to be retrofitted for residential applications. Since Habitat for Humanity is a charitable organization, retrofit services were donated or provided



Figure 12: Guardrail on Gable End of Roof Assembly

at cost by local partners. The expenses for stair covers and guard railing were minimal, and these are reusable, which helps to control costs. Use of storage and transportation bins ensures the integrity of the fall protection equipment between builds. PFAS is used by a trained carpentry professional for a brief period of time at each build, but not by volunteers as they lack training and vary in size and shape. Permanent roof anchors provide anchorage for maintenance and repair activities, protecting homeowners and repair professionals.

Instead of avoiding contact with OSHA, Habitat for Humanity regularly consulted OSHA for technical assistance, and OSHA provided the assistance required. Relying on inexperienced, volunteer workers forced Habitat for Humanity to find creative solutions to comply with OSHA's fall protection standards. The fall protection methods and equipment described in this case study may not all be applicable for commercial home builders, who have very short construction timelines and more intricate homes. Competitive home builders have an advantage transitioning to conventional fall protection as

many of the carpenters they employ are usually trained to use personal fall arrest systems; however, they may be disadvantaged as their workforce most likely feels competent working at leading edges and standing in the webs of roof trusses. Lackadaisical attitudes of an experienced workforce, concerns about the time required to use fall protection, and well-engrained building habits may be the most difficult things to overcome when transitioning to use of conventional fall protection during home construction. Habitat for Humanity redesigned many of their building practices around fall protection and described making a major “cultural shift” to embrace conventional fall protection.

There is a need for resources to help builders and contractors transition to using conventional fall protection. The Residential Guidance Document lacks details that are needed to make informed decisions about fall protection equipment and methods. The national fall prevention awareness campaign described above provides many resources that have been widely accessed; however more needs to be done. As the need for safety nets in residential construction increases, safety net manufacturers will need to design and manufacture brackets to allow the safety net to couple with the wood components used in home building. Using equipment rental vendors to research options for scaffolding and renting the scaffold boards instead of purchasing them worked well in this case study. We believe that rental equipment companies can play a significant role in residential fall protection (Evanoff and Kaskutas, 2012). A multifaceted approach is needed to address the epidemic of falls in residential construction worker falls, which claimed the lives of another 27 workers in 2011 (Bureau of Labor Statistics, 2012).

Acknowledgements

This study was supported by a research grant from the Center for Construction Research and Training through the Centers for Disease Control/National Institute of Occupational Safety and Health, Grant #U60 OH009762.

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Techniques for Building an OSHA Compliant Guardrail Structure

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Abstract

In the construction industry, workers falling to a lower level has been the primary cause of fatalities according to the Bureau of Labor Statistics Census of Fatal Occupational Injuries database. From 2006 to 2010, an average of 353 construction workers died annually as a result of falling to a lower level. An average of 126 workers (36%) died when falling from unguarded roof edges, and through roof and floor holes or skylights. The National Institute for Occupational Safety and Health evaluated the strength of job-built guardrail structures around an opening. The study focused on a 2' x 4' opening typical of residential skylights. Nine full-time residential carpenters built guardrails for strength testing.

Guardrails were constructed with 2" x 4" lumber and 16-d duplex nails. The strength test determined if each guardrail could support a 200-lb loading on the top rail as required by the OSHA Fall Protection Standards (Subpart M). A quantitative pull test was then done to measure the strength and integrity of each guardrail. All nine guardrails passed the 200-lb drop test, and the strength test results ranged from 161 to 575 lbs. Three of the nine test subjects were randomly selected to construct similar guardrails using 3-inch all-purpose screws instead of nails. An average of 75 screws were used per guardrail compared to an average of 85 nails per guardrail. The strength of the structures built with screws was more consistent, and had a 67% increase in overall strength with respect to the nail structures and the strength test results ranged from 395 to 470 lbs. The overall strength and integrity of the structures was directly related to the construction techniques used by each subject. The successful construction techniques were determined to be the following: the orientation of vertical support posts relative to the applied loading, anchoring the vertical posts inside the opening, the overlapping of the rails of the structure, and the number, type, and orientation of the fasteners.

Introduction

Worker fatalities caused by falls

When working on steep-sloped roofs or near unguarded edges, openings, or stairs, employers are required to

protect construction workers through the use of guardrail systems, covers, safety net systems, or personal fall arrest systems, according to OSHA regulations, 29 CFR 1926.500-503 (Subpart M – Fall Protection). Workers falling to a lower level has been the primary cause of fatalities in the construction industry since the Bureau of Labor Statistics started the Census of Fatal Occupational Injuries database in 1992. For the period 2006-2010, an average of 1,001 workers died each year in the construction industry. Of this total, an average of 353 (35%) died each year by falling from elevations. More specifically, 126 workers died each year when falling from unguarded roof edges, and through roof and floor holes and skylights. These are all work situations where workers could be prevented from falling by installing guardrails, either job-built or commercially available systems.

NIOSH study

The evaluation of the effectiveness and strength of a job-built guardrail versus a commercially available guardrail system was reported in Bobick and McKenzie (2005). This study was conducted by NIOSH engineers from the Division of Safety Research. It was limited in scope and focused on protecting a typical residential skylight opening (2' x 4'). The nine test subjects were full-time residential carpenters. The subjects were asked to construct a guardrail structure around the perimeter of the opening that they thought would protect a person from falling into it, using construction-grade white pine 2" x 4" lumber and 16-d duplex nails. (The duplex nails were used to facilitate disassembling the structure after testing was completed.) All nine carpenters were informed that the top rail had to meet the OSHA specification (29 CFR 1926.502(b)(1)) that the "top edge height" had to be "42 inches...plus or minus 3 inches...above the walking/working level." The subjects were not aware of how the structure would be tested. The nine subjects constructed two job-built guardrails – one for a flat surface and one for a sloped (4/12) surface. This report focuses on the results related to the flat surface.

Drop testing for OSHA requirements

The job-built guardrail systems were evaluated to determine whether they complied with OSHA regulation 29 CFR 1926.502(b)(3). This regulation states that,

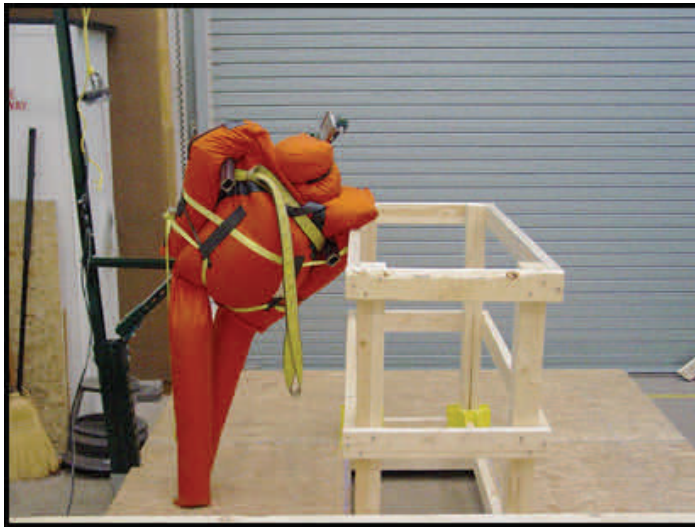


Figure 1. 200-lb Drop Test

“Guardrail systems shall be capable of withstanding, without failure, a force of at least 200 pounds (890 N) applied within 2 inches (5.1 cm) of the top edge, in any outward or downward direction at any point along the top edge.” (Mancomm, 2012, p. 323) A testing system was developed to simulate the real-world scenario of a worker, weighing more than 200 lbs., tripping and falling into the top rail of the guardrail structure. A fire-rescue test manikin was mounted on a steel frame and was hinged at knee height to simulate the motion of a person when they trip and fall, as shown in Figure 1. Each drop of the manikin was calibrated to ensure that the applied force was always greater than 200 lbs. The test set-up and calibration procedure was described previously (Bobick *et al.*, 2010).

Pull-to-failure strength testing

The ultimate strength of each guardrail constructed was evaluated individually by using a NIOSH-developed pull-to-failure (PTF) test. The testing philosophy for this test

was to quantitatively evaluate the ultimate strength of each guardrail configuration. The PTF test imposed a sustained force (lasting 2-3 seconds), which far exceeded the OSHA 200-lb falling test duration. A maximum pulling force of 800 lbs was generated using a 2-inch hydraulic cylinder, a battery-operated hydraulic pump, and a cable and pulley system as shown in Figure 2.

PTF and Drop Test results

Results from the testing of job-built guardrails built for the flat surface indicated that all of the structures passed the OSHA 200-lb loading requirement, as conducted in this research study. However, the pull-to-failure results ranged from 161 lbs to 575 lbs.

Visual analysis of the PTF results

The ability of a structure to withstand a single impulse, shock, or instantaneous loading (OSHA 200-lb drop test), does not correlate to its ability to withstand a sustained dynamic continuous load, such as found in the PTF testing. The linear frictional forces between the nails within the wood structure and the dynamic energy absorption



Figure 2. PTF Testing system



Test Subject #7

16-d duplex nail fasteners

PTF Strength
249 lbs

Nails Used
105

Construction Time
52 min.



Figure 3. Subject #7 PTF Testing Results Using Nail Fasteners

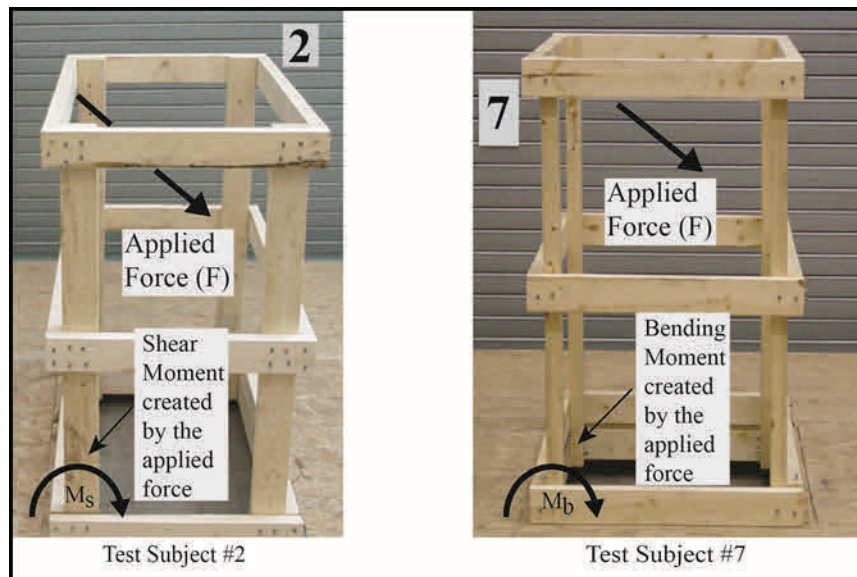


Figure 4. Shear Moment and Bending Moment Cases

(resilience) as a whole were substantial enough to resist a low impact, instantaneous 200-lb force. However, the sustained loading applied from the PTF test exceeded the linear frictional forces between the nail fasteners and the wood structure. Once the linear friction forces were exceeded, the structure began to move dynamically thus introducing a combination of bending and shear forces on the fasteners. The overall strength was then influenced by the construction techniques used. An example of the PTF test results and a before and after picture of the guardrail is shown below in Figure 3.

When guarding a hole or opening in a floor or flat roof, the direction of the worker falling (the applied loading) on the structure is not known, so an applied force in all directions should be considered. The applied loading (or force) will create a bending moment at the base attachment points. This will act like a giant crow bar and will either pull the fasteners out of the base or try to twist (or shear) the fasteners off the base. During the testing, one subject constructed the guardrail with the base fasteners being in shear during the evaluation testing (subject #2). That overall PTF strength was measured at 575 lbs. The others had the base fasteners in bending and the PTF strength range was 161-319 lbs. Examples of these two cases are shown in Figure 4.

Fastening the toeboard, midrail, and top rail to uprights was mostly constructed with overlapping segments. The number of fasteners used and the orientation of the boards varied. The predictability of how the midrails and top rails would react (splitting or not splitting) was dependent upon the fastener configuration. The lumber that the subjects used was construction-grade. An effort was made to select “clear lumber” for the 500 board feet of lumber used in the study. Despite being extra careful, some of the lumber had knots in them that contributed to premature failure during the pulling test. Some examples of how the wood split during the testing are shown in Figure 5.

The most critical factor identified to increase the overall strength and integrity of the guardrail structure was the construction practice of overlapping and fastening the toeboard, midrail, and top rail as shown in Figure 6. This is an example of a top rail that has been overlapped and fastened with two nails.

To emphasize the importance of overlapping the rails, the structure constructed by test subject number eight will be highlighted. The subject did not overlap the rails and had a respectable PTF strength of 249 pounds, but at the end of the test, the structure broke apart and introduced other safety concerns. It no longer provided adequate fall protection and had exposed nails and projecting cross pieces, as shown in Figure 7.

Guardrail system strength was not completely dependent on whether the boards split or did not split. Planning fastener patterns can help eliminate some of the splitting. The nail fasteners should be equally distributed into the board. When fastening into the short side of the 2" x 4", two fasteners should provide acceptable fastening strength. When fastening into the wide side of the 2" x 4", three fasteners in a triangle configuration should provide acceptable fastening strength. More than four fasteners in any one board was not a determining factor in the overall strength of the structure. Depending on the wood quality, sometimes five fasteners made the board crack before the loading was applied.

Additional testing using screw fasteners

At the conclusion of the initial study, the researchers wanted to evaluate and compare the strength of a similar job-built guardrail constructed with screw fasteners. For this additional testing, three of the original nine carpenters (subjects 1, 7 and 8) were randomly selected to return to complete the original task (as subjects 11, 12 and 13 respectively), except the fasteners were changed from 16-d duplex nails to 3-inch all-purpose Phillips head screws. Figure 8 provides the PTF test results and shows before and after photos of the guardrail. Table 1 indicates that



Figure 5. Examples of Wood Splitting



Figure 6. Overlap Mid and Top Rails

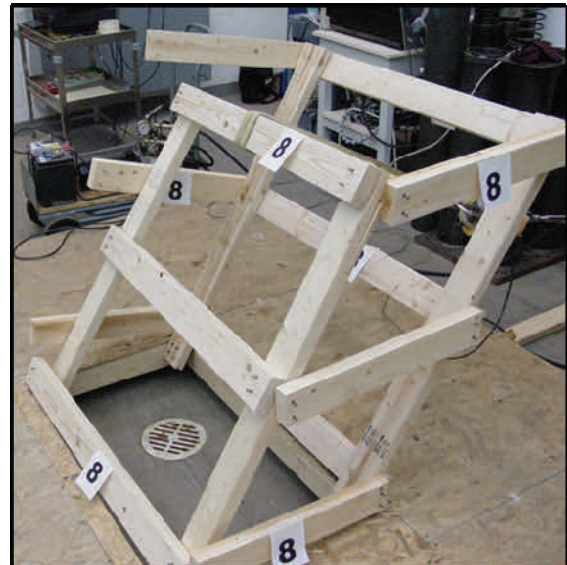


Figure 7. Subject 8: Structure after PTF Testing



Before Testing

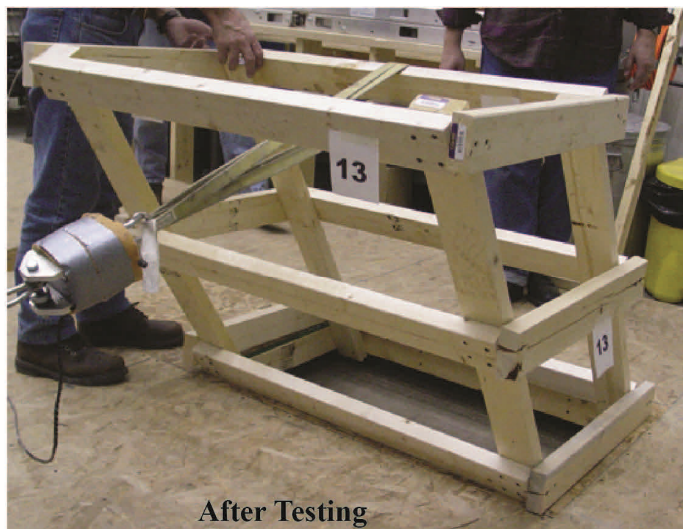
Test Subject #13

3-inch all purpose screw

PTF Strength
453 lbs

Screws Used
88

Construction Time
41 min.



After Testing

Figure 8. Subject #13 PTF Testing Results Using Screw Fasteners

Table 1. PTF Strength, Number of Fasteners, Construction Time

Test Subject Number		PTF Strength (pounds)		Number of Fasteners		Construction Time (min)	
Nails	Screws	Nails	Screws	Nails	Screws	Nails	Screws
1	11	260	470	82	78	25	22
7	13	249	453	105	88	52	41
8	12	280	395	64	60	24	20
Mean		263	439	84	75	34	28
Percent Change (Screws vs. Nails)		+67%		-10%		-18%	

the screw fasteners provided superior strength with fewer fasteners needed, and had reduced construction times. The benefits of using screw fasteners were discussed previously (Bobick *et al.*, 2010).

Discussion

Anchoring

Interestingly, what was initially thought to be a straightforward task actually resulted in nine different designs. Some of the professional carpenters did not attach the vertical support posts to the inside of the opening, and instead attached the base of the guardrail structure to the roof surface. The job built guardrail structures attached to the surface had the lowest PTF test results. The carpenters who attached the vertical support posts to the interior surface of the hole used between three and five

16-d duplex nails. The testing showed that three or four nails gave acceptable fastening strength. Using five nails did not result in a measurably stronger structure. Subjects who used three nails spaced them out equally, which lessened their contribution to the splitting of the vertical post at the attachment point. The PTF testing evaluation was an extreme condition, which quantified the overall strength of the structure, and was not intended to represent a real-world event. When subjects constructed the midrails and top rails, there was a lack of consistency in the construction. Most subjects used three or four nails to attach the midrail or the top rail, while some only used one or two nails to attach to the vertical posts.

Job Built Guardrail Structure Installation Recommendations

Orientation of Vertical Posts

Since the direction of the worker falling (*i.e.*, the applied loading) on the structure is not known, applied force in all directions should be considered when guarding a hole or opening in a floor or flat roof. In order to do this, the configurations of two of the posts located diagonally should be turned 90 degrees as shown in Figure 9 and Figure 10. This will ensure that two of the base fasteners are in shear while the other two will be in bending when the applied load is perpendicular to one of the top-rails. When the load is applied at the corners, then all four posts will have a combined shear/bending loading on the base fasteners. This configuration should result in a structure that is 34%-40% stronger when using 16d nail fasteners and 10%-19% stronger when using 3-inch all-purpose screws, measured under the same testing conditions. The posts should be fastened to the base using 3 or 4 fasteners each.

Fastening techniques

The overall strength of the structure increases when the ends of the rails overlap and are fastened to each opposing rail. The number of fasteners should be limited; more is not always better. Fasteners should be staggered if possible to prevent the wood from splitting under loading. The nail fasteners should be equally distributed into the board. When fastening into the short side of the 2" x 4",

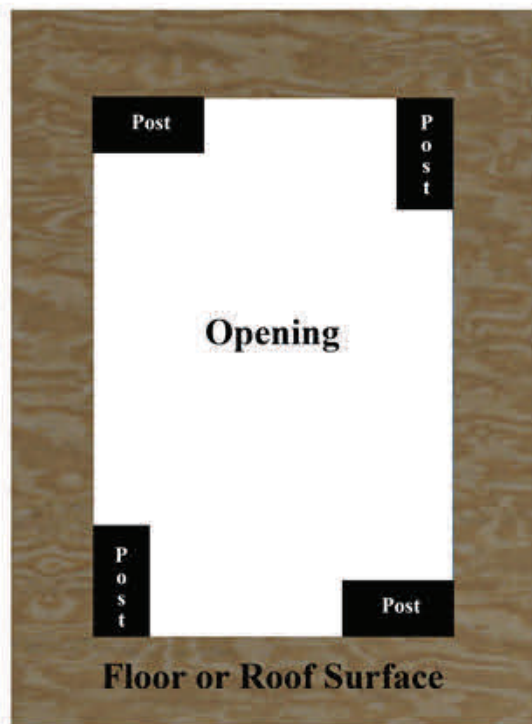


Figure 9. Top View with Turned Posts

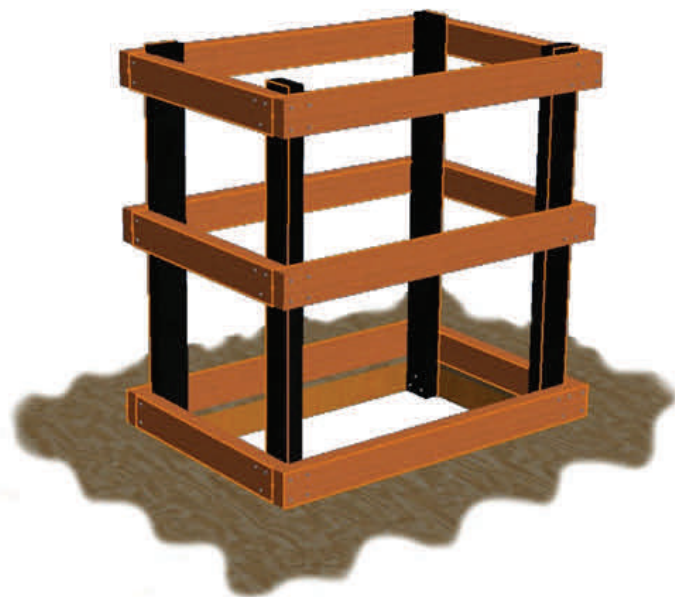


Figure 10. Perspective View of Guardrail



Figure 11. Overlapped Rails and Fastener Placement

two fasteners should provide acceptable strength. When fastening into the wide side of the 2" x 4", three fasteners in a triangle configuration should provide acceptable strength. This is shown in Figure 11.

When constructing a guardrail, the overall strength can be maximized by using screw fasteners. Even though only three test subjects were used to reconstruct the job-built flat configuration using 3-inch coarse thread all-purpose screws, the data indicated that using the screws resulted in, on average, significantly stronger configurations that were built slightly quicker than the same guardrail system using duplex 16-d nails (Bobick *et al.*, 2010). The three test subjects that conducted these extra tests indicated that using nails was more typical, but that they often used screws on the job and felt that this was a fair test.

Future Work

An additional point to consider is that there are higher quality screw fasteners that are made of high-strength steel and have a self-drilling capability. These particular fasteners have been subjected to independent laboratory tests, as contracted by the screw manufacturer, to determine their strength characteristics when installed in different materials. The use of this type of fastener could result in a stronger guardrail system that may be installed quicker than the typical all-purpose screw fasteners. Additional laboratory testing using these more sophisticated fasteners is planned for the future.

Conclusions

Based upon the aforementioned results, it is possible to construct a job-built OSHA compliant guardrail, as evaluated with the described OSHA 200-lb drop test. The job-built guardrails can be safely constructed using construction-grade 2" x 4" lumber and appropriately sized nails or screws.

The job-built guardrails could have inherent weaknesses due to the non-homogenous building material. This limited study exposed multiple weaknesses and strengths. With proper planning, some of these weaknesses can be engineered out to build the strongest temporary structure possible. The method of constructing, the type of fasteners, and the fastening techniques used are key planning factors to build an OSHA compliant guardrail structure. The overall success of constructing a job-built guardrail structure is proper planning. Good safety practice requires that job-built guardrail systems be constructed of new 2" x 4" lumber for the system to obtain the maximum possible fastening strength. The practice of re-using old materials is unsafe and should be avoided.

Acknowledgement

The authors would like to acknowledge Mr. Doug Cantis, Physical Science Technician, Division of Safety Research, NIOSH whose help during the planning of the testing, the construction of the test fixture, and assistance during data collection was extremely valuable and sincerely appreciated.

Disclaimer

The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health

The National Institute for Occupational Safety and Health (NIOSH) is a research agency. It does not conduct any type of certification testing of fall-protection or fall-prevention equipment.

Mention of any company names or products is for informational purposes only, and does not constitute any endorsement by NIOSH, or any agency of the Federal government.

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Personal Fall Arrest System Anchors in Residential Construction

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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, which could cause a loss of future business
- Loss of respect and use by 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 metal plate connected wood trusses. Wood trusses have been specifically designed to carry planar vertical loads, but are not equipped to resist lateral loads. This paper will review the 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 are considered impractical due to setup time. Therefore, this paper focuses on the 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 relatively 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



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

1800 lbs for those wearing a body harness. Therefore, 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 construed as misleading. 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. This should not be taken as a slight towards the strength of wood elements or a statement that fall arrest systems cannot be used with residential construction. The use of a designed fall arrest system (See OSHA 29 CFR 1926.502(d)(15) above) is needed for wood construction, which requires correct detailing of the anchorage connection.

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 author's 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 5,000 lbs or 3,600 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 light-frame wood trusses are not designed for, but is possible due to a worker falling.

Horizontal Application of Load Tester (HALT)

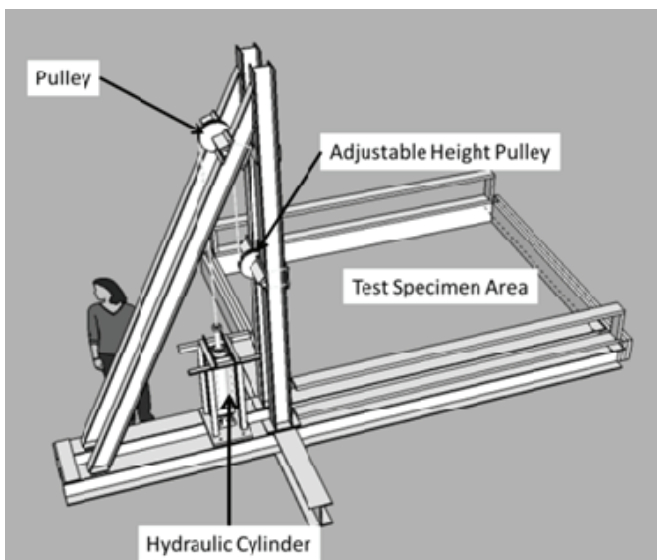


Figure 2. Diagram of the Horizontal Application of Load Testing (HALT) with Stem Walls Positioned for Eave Loading

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 vertically 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. 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. This section is to serve more as an executive summary of findings rather than a complete description of the test methods.

Fall Arrest Anchor Used For Testing

The 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. The bracket is very strong, consisting of a 1 inch by 1 inch square solid steel section. 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.



Figure 3. PFAS Anchor Used for Testing

Monoslope Truss Testing

Initial testing of single trusses used a monoslope truss with 3:12 and 6:12 pitches (Figure 4). Because of the limitations of the laboratory arrangement, only trusses 10 feet in span could be tested with the HALT applying load along the supports. The monoslope configuration was thought to give a worst case scenario of testing at the truss peak, which did produce higher moments in the trusses. Monoslope trusses 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 very low compared to the loads needed for creating 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 for most 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).

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

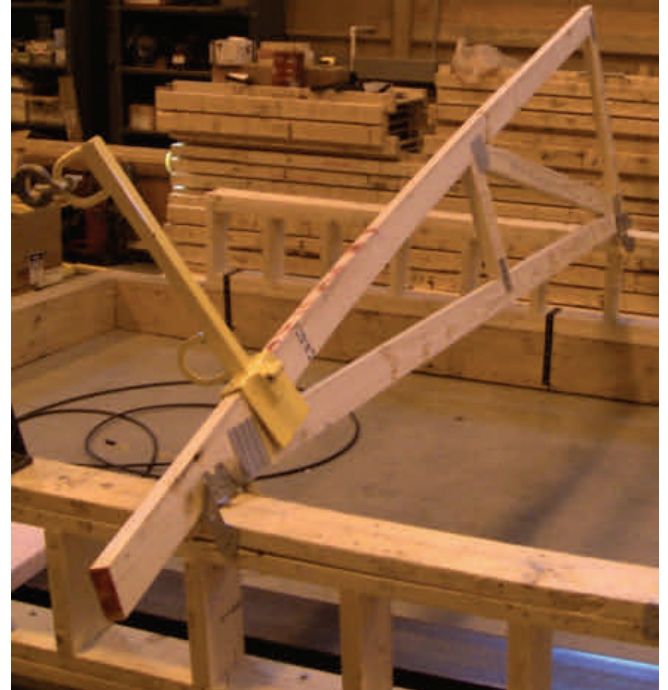


Figure 5. Rotation of Truss At Truss-Wall Connections Due to Lateral Loading



Figure 4. Testing of Monoslope Trusses Using HALT

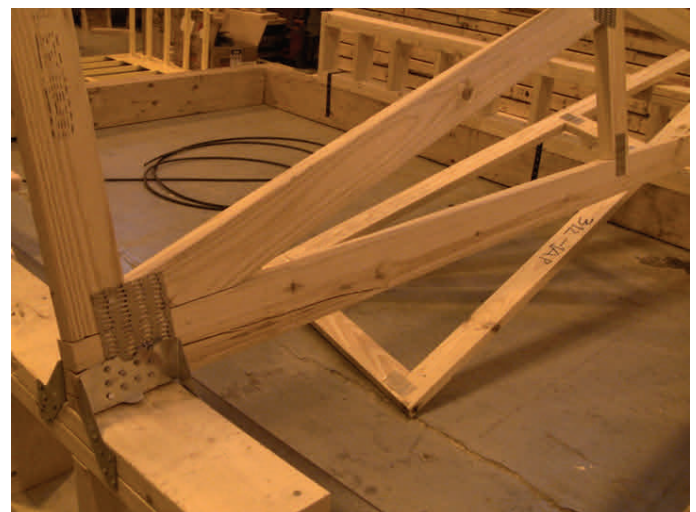


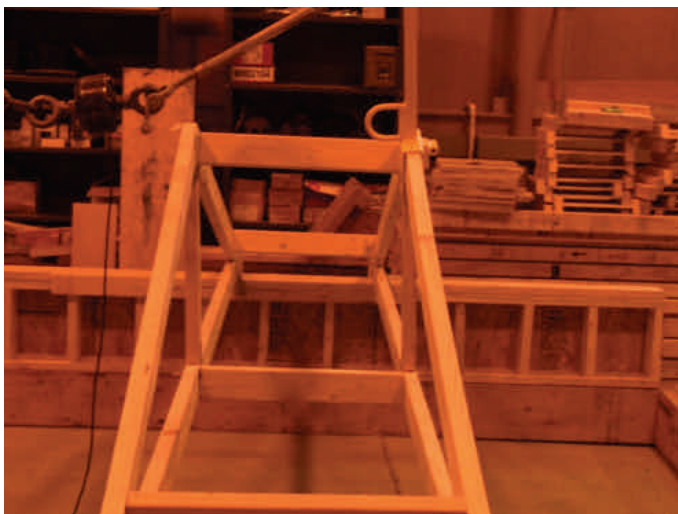
Figure 6. Fracture of Bottom Chord of Truss Due to Lateral Loading

Displacement Rate Testing

Displacement rate in wood design 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, 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 1. Load values ranged from 121 lbs. to 149 lbs., demonstrating that little effect of displacement rate. Figures 7, 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 diagonal bracing in place. Since the wood-metal connections were the location of failures, 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 pattern of the impact load as the displacement loads applied 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.



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

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 should show that two trusses without diagonal bracing have very little resistance to lateral loads.

Effects of Different Bracing

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, lumber 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

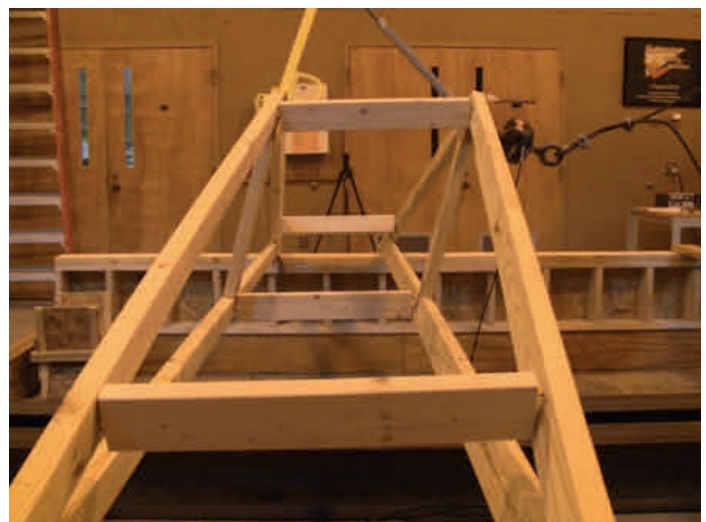


Figure 8. Displacement Rate Trusses During Loading

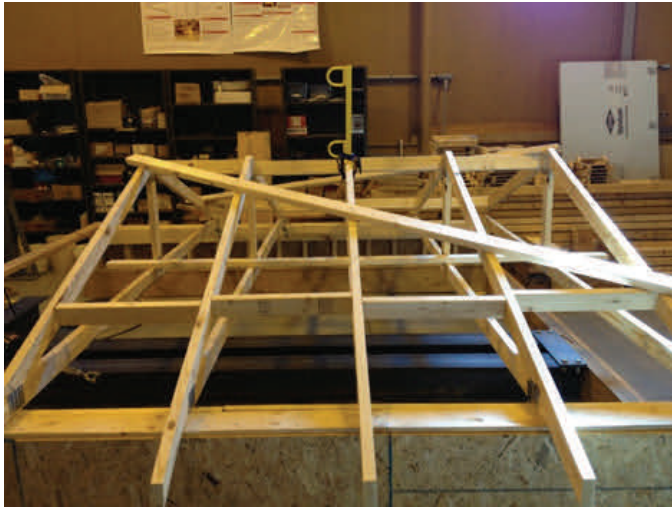


Figure 9. Five Kingpost Truss System Used for Bracing Testing

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.

Another observation from testing the PFAS bracket was the action of the bracket itself. 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



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
Bracing Over Top of Trusses	752
Metal Engineered Brace Between Trusses	571

well as several of the braces loosening as the truss system deflected. The blocking between truss nails withdrawn from the truss member (Figure 10). The over the top bracing nails did not pull out, but some splitting of the truss top chord was noted where 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 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 some rotation is noticeable in several of the trusses.

The loads for the over the top blocking 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 designers considered the entire load path of the weight of the person through the structure. All connections of the fall arrest system to truss members and the wall below must 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 over-



Figure 11. Loading of Five Truss System with Over the Top Bracing and Splitting of Truss



Figure 12. Metal Engineered Bracing Pulled From Truss After Failure

stressed. It is important that all fall arrest systems attached to trusses be designed by a qualified individual for the particular construction situation present.

Acknowledgement

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 authors and do not necessarily represent the official views of the CDC.

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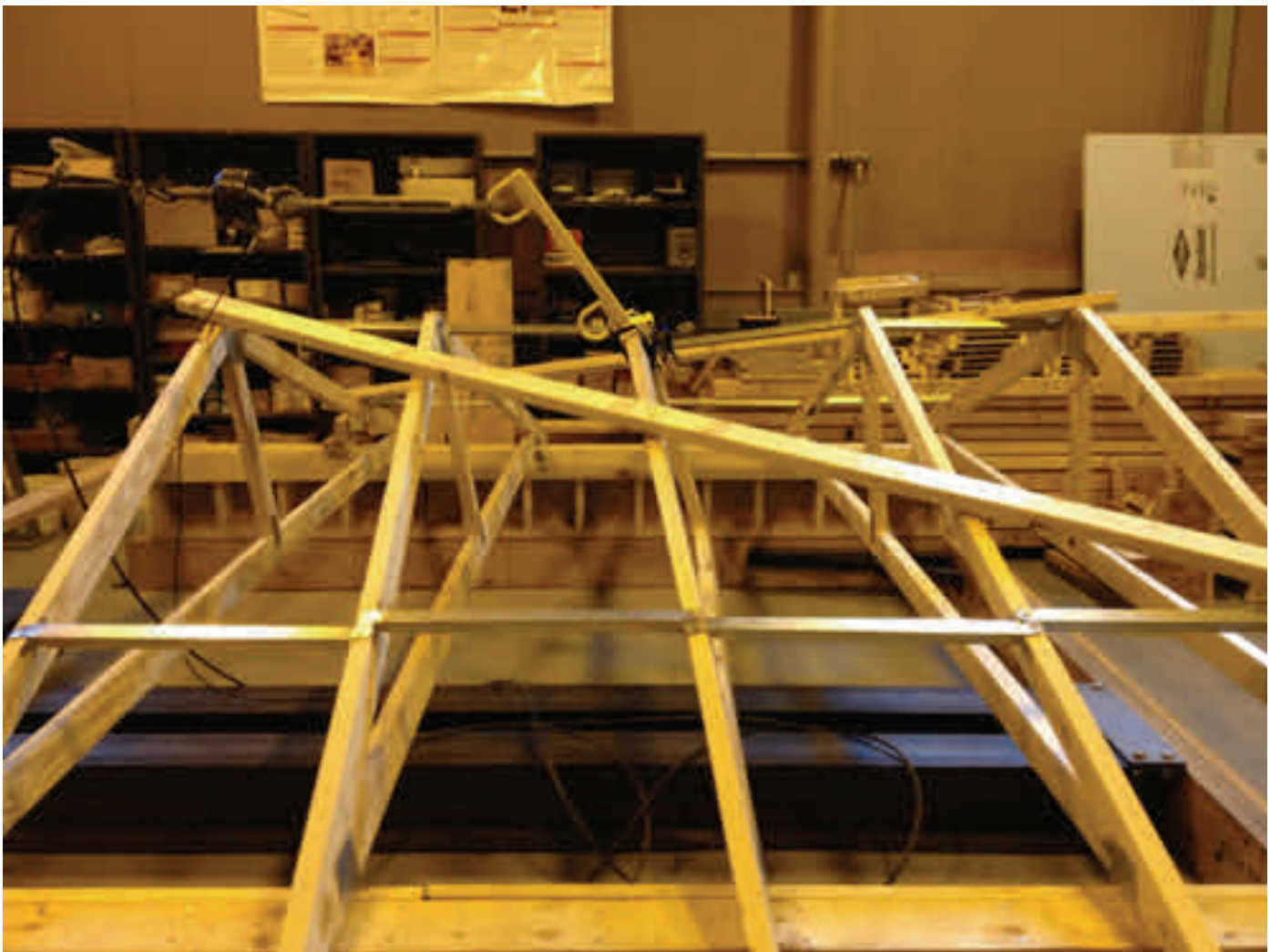


Figure 13. Loading of Five Truss System with Metal Engineered Bracing

Observations of Truss Assembly Lifting to Decrease Fall Hazards on Roofs

Daniel P. Hindman, Ph.D, P.E., and John C. Bouldin, Jr., Ph.D.

Recent OSHA changes to fall arrest requirements on residential construction sites have left builders with questions and concerns over compliance. Conventional methods of unprotected 'leading edge' construction involving roof system erection are being limited and new methods or techniques to work safely and quickly are needed. Many contractors and design professionals may be caught in the middle – forced to change methods by OSHA and experiencing resistance to change by workers.

One method that has been developed by several companies and groups is the use of truss rafting, or constructing roofs or roof sections built on the ground and lifted into position. The advantage of truss raft is that worker fall hazards are minimized, since the majority of work is conducted on the ground rather than at height. Productivity may also be increased due to the convenient placement of materials, difference in visual cues, and even the ability to quickly take a break and return to work. The lifting process is usually very quick using conventional craning methods already employed on many construction sites. After the roof is in place, the rafted structure

provides a place to attach fall arrest anchors as needed for subsequent construction operations.

Site Visit

Recently, we visited a construction firm assembling a series of three story townhomes in Richmond, Virginia to observe several roofs being rafted into place. The builder, Eagle Construction, is a full service independent Virginia-based homebuilder. The townhomes being constructed (Figure 1) had a variety of roofing profiles – some consisting of gable-style roofs of various pitches, while others featured a gambrel roof with rooftop deck.

Two of five roof assemblies for a particular grouping of homes were able to be constructed using rafting, while the other roof profiles were constructed by more conventional methods of lifting and installing individual trusses. The rafts were constructed on the street in front of the townhomes, and each roof was approximately 20 feet long and 35 feet wide. Permanent bracing and sheathing was installed on the trusses (Figure 2) as well as frames for false dormers (Figure 3). Because of the size and weight of the rafts constructed, the construction firm

decided against installing the roof covering materials until after the roof system was lifted into place. The site supervisor felt that worker safety and productivity was dramatically improved by constructing the truss systems on the ground.

At the present time, there are no prescriptive guidelines for rafting trusses and all lift designs and rigging should be verified by a registered design professional. Eagle Construction retained the services of a professional safety consultant to advise



Figure 1. Townhouse elevations.



Figure 2. Bracing and Sheathing Installed



Figure 3. Trusses, Sheathing, and Front Gable Installed



Figure 4. Lifting Beam Placement within the Truss Raft Structure

them on the methods for rafting these truss assemblies. A 40-ton crane was used for lifting the rafts and the single trusses into place on the roof. To facilitate the rafted lift, workers assembled two 3-ply 2x6 beams that extended the entire width of the truss assemblies and installed them within the completed roof assembly on the ground. These beams were placed at approximately the third points underneath a plated web connection (Figure 4). The workers then cut small holes in the sheathing to thread the lift straps, which were looped around the beams and attached to the crane's lift cable.

The truss assemblies were then raised off the ground a few feet and examined for proper balance, then lifted into position (Figure 5). Workers in the upper story of the structure helped to adjust the final placement of the truss system, and made permanent connections to the previously erected platform framing. The total time for lifting and attachment (i.e. time from when crane lifted the raft until the rigging was slacked) was approximately 15 minutes for each roof.

Conclusion

From this observation, truss rafting appears to have great potential for roof construction in the current safety regulatory climate. Anecdotal evidence suggests that worker productivity was increased, and worker safety was significantly improved, but measurements to quantify and validate these observations are still needed. Potential barriers to use of truss rafting appear to be a lack of knowledge of and experience with the practice, and design of the rigging methods. Construction firms interested in using this method should seek the advice of a registered design professional with experience in lifting truss rafts.

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Figure 5. Lifting the Truss Assembly into Place