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Knowledge Gaps and Emerging Issues for Fall Control in Construction

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ABSTRACT This chapter reviews the history and ongoing multidisciplinary research to address the prevention of falls from elevation in the construction industry. It touches on both personal and environmental factors that affect construction falls, as well as their often devastating consequences, including the number of people affected and businesses impacted. It outlines issues, often difficult, related to falls from roofs, ladders, and scaffolds. Because falls involve a complex combination of safety controls, safety culture and management, and worker behavior, this chapter covers each. The chapter addresses efforts toward sustainable solutions, ranging from education, training, and behavior to engineering,

controls, and prevention through design, in addition to administrative issues. Because it has brought a lot of attention to the issue of falls in construction and effective ways to prevent them, the chapter also covers the national falls prevention campaign. Finally, research needs and gaps are presented, with the goal of advancing the science of preventing construction falls.

KEY WORDS: *construction, safety, falls, ladders, roofing, scaffolds, towers, lifts, prevention, training, campaign.*

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27.1 Introduction

Falls from elevation are the leading cause of construction industry injuries and deaths in the United States. According to 2010 data from the Bureau of Labor Statistics (BLS), falls to a lower level accounted for 251 of 751 deaths in construction, just under half (49%) of the total number of falls in all private industry that year (www.bls.gov/iif/oshwc/cfoi/cftb0258.pdf). Most construction fatalities occurred when workers fell from roofs, ladders, and scaffolds. According to a study by the Center for Construction Research and Training (CPWR), small construction companies (with 10 or fewer employees) had the highest percentage of fatal falls (64%). In addition, laborers, carpenters, and roofers were the construction workers with the largest number of fatal falls. Furthermore, workers with less than a year in the industry accounted for 56% of fatal falls (Dong, 2010).

Construction workers are more likely to die on the job than workers in any other industry, and falls from elevation (often one story or higher) take the heaviest toll (Dong et. al., 2014). Approximately 4400 occupational fatalities occurred in 2012 (BLS, 2013), and about 18% of these were in the construction industry. More than a third of the construction fatalities that year were caused by falls, of which 35% were from a roof. Half of the workers fell from the roof edge, and the others fell through an existing roof hole, skylight, or collapsing roof surface. Details on the causes of these falls are often unreported.

The costs of fatal falls and injuries in construction are high, including heavy burdens on workers, families, employers (often small businesses), and the broader society in general. Even when workers survive, many have significant nonfatal injuries, such as traumatic brain injuries for example, or other issues requiring lengthy rehabilitation. These place enormous emotional, medical, and financial burdens on their families. Falls also result in significant costs to employers, including lost productivity, loss of skilled workers, and increased workers' compensation costs.

Because of the tremendous toll of these injuries and deaths on the nation's workforce, their families, employers, and society, extensive research has been conducted and is continuing to address this problem, to better understand their causes, and to design technologies and methods for advancing their prevention, with the ultimate goal of eliminating falls in construction. Researchers are assessing gaps in knowledge and are encouraging the development and adoption of new technologies and procedures. Studies with a wide range of methods have examined many factors involved in falls, including the populations affected and the situations and tasks most commonly associated with them. Additional research has focused on different approaches to reducing the severity and likelihood of construction falls. Despite these substantial efforts, however, more studies are needed for progress to continue. The following pages describe recent work and emerging issues, as well as some ideas on where research is headed in this important area of construction safety and health.

27.2 Gaps and Emerging Issues

27.2.1 Risk Factors Influencing Falls

Many studies have focused on the factors associated with falls in construction. These factors can generally be placed into two categories: environmental factors (relating to the worker's surroundings) and personal factors (relating to the individual who suffered the fall). Much of the information available on both factors is based on surveillance and epidemiological studies of falls in construction.

27.2.1.1 Environmental Factors

Environmental risk factors associated with construction falls include surface properties (e.g., strength, stability, and slippage), incline and restrictions of the support surface, and visual elements. Surface properties involve issues such as the coefficient of friction between the worker's shoes and the walking surface (Hanson et al., 1999). In roofing, other surface factors that may be consequential are unstable elements such as roof shingles, as well as potential obstructions or uneven surfaces, which are all tripping hazards. Another surface property risk is posed by fragile materials that can cause falls through the surface. Shoe style also affects workers' walking stability at elevation (Simeonov et al., 2008). Challenging work environments, such as narrow walking surfaces, result in modified walking for balance control, which points to the potential role of footwear in loss of balance. Weather conditions (e.g., rain, wind, or even dew), furthermore, can affect the walking surface. A study in Hong Kong showed that the highest percentage of falls occurred in August, which is the hottest month and has the most rainfall (Wong et al., 2005). The fewest falls occurred during February, one of the driest months of the year in that city.

Although some roofs are flat, many have pitch for drainage. In general, low-sloped roofs have a pitch ratio of $4-12$ (vertical to horizontal), and for steep-sloped roofs, the ratio is >math>4-12</math>. As roof pitch increases, the likelihood of slipping rises, because higher coefficients of friction are needed between the roof and the worker's shoes. Finally, a considerable amount of research has been conducted on visual aspects that influence falls. Hsiao and Simeonov (2001) reported that worker balance, as well as depth perception and detection of obstacles or other potential hazards, is affected by elevation.

TABLE 27.1

Types of Falls and Related Activities

Fall Type	Associated Activity
Falls through floors	Unguarded openings or inadequate fall protection
Falls from girders or structural steel	Bodily action or improper use of PPE
Falls from roof edge	Bodily action or being pulled down by heavy objects
Falls through roofs	Noncompliance with scaffold standards
Falls from ladders	Overexertion or use of unsafe ladders and tools

Chi et al. (2005) studied over 600 fatal construction falls, using accident reports to determine each victim's age, gender, experience, and use of personal protective equipment (PPE); the fall site; and the company size. Approximately 92% of the fall victims were men. Also, for a variety of reasons, the risk of falling was higher for small businesses, and over 80% of the fatal falls were of workers with less than 1 year of experience. Falls from scaffolding (30% of falls) were associated with violating government standards and bodily action (i.e., climbing, walking, or leaning against something). The associations between types of falls and specific associated activities found by Chi and colleagues are provided in Table 27.1.

Primary fall prevention measures that were discussed in Chi et al. included handrails, guardrails, surface opening protections, crawling boards/planks, and stronger roofing material. Secondary prevention measures included travel restriction, fall arrest, and fall containment systems.

Fong et al. (2005) investigated lower-extremity kinematics of walking on slippery simulated construction surfaces. Variations in footwear, flooring, and contaminants were tested. The dynamic coefficient of friction was measured for each condition. Fifteen men wearing fall harnesses walked and avoided slips. Their movements were measured with a motion analysis system. Recommendations to prevent slips included increased stance and stride time, shortened strides, decreased speed, and gentle heel strike. Hanson et al. (1999) studied friction and gait biomechanics for actual slips and falls. The goal was to develop a method for estimating the probability of slips and falls. Subjects wearing safety harnesses walked down a ramp at various angles (0°, 10°, and 20°) on either a tile or carpeted surface under dry, wet, or soapy conditions. The dynamic coefficient of friction of shoe, floor surface, and contaminant interfaces was measured. Friction was assessed by examining the foot forces during walking when no slips occurred. Slips were recorded and categorized to develop a model of the probability of a slip or fall. Slips and falls increased as the difference between the required coefficient of friction and the measured dynamic coefficient of friction increased.

Finally, another environmental factor that impacts construction falls is the worksite safety culture and safety climate. Safety culture is associated with deeply held beliefs, attitudes, and values within an organization. Safety climate is closely related to safety policies and procedures within the organization. Some of the important elements that influence safety climate within an organization include worker participation, management commitment, leadership, training, communication, and trust. Each of these elements can play a significant role in reducing the likelihood of falls in construction (CPWR, 2013).

27.2.1.2 Personal Factors

Dong et al. (2009) studied trends in fatal falls from roofs in US construction from 1992 to 2009. Their analysis of data from the BLS Census of Fatal Occupational Injuries (CFOI) and

the Current Population Survey showed that falls from roofs accounted for one third of fatal falls in construction during the period. Approximately 67% of deaths from roof falls occurred in small construction businesses (i.e., having 10 or fewer employees). Roofers, ironworkers, roofing contractors, and residential construction workers were most at risk for fatal roof falls. Elevated rates of roof fatalities were found also among workers aged under 20 years old or more than 44 years old, Hispanics, and immigrants (Dong et al., 2013). Dong (2010) recommended that prevention strategies target these high-risk workers.

Hispanics represent over 25% of US construction workers and are more likely to experience fatal falls than non-Hispanics. Approximately 17% of the US population is Hispanic. The proportion of fatal falls among Hispanic construction workers increased from approximately 37% of all fatal falls annually during 1992–2002 to 40% of all fatal falls in 2006. The risk of fatal falls is higher for Hispanic workers who were not born in the United States. Nearly 80% of the Hispanic workers who died from falls in 2003–2006 were foreign born, and many were young and inexperienced. Nearly 65% of Hispanic workers who died—compared with about 53% of white, non-Hispanic workers who died—had been employed for less than a year (Dong et al., 2009). These differences in fall rates could be related to factors such as employers' failure to train these workers adequately in relation to their pre-employment education or attainment of job skills; difficulties in understanding or implementing training due to lower English language proficiency; and assignment of these workers to jobs with higher exposures to fall risks.

In another study, Chau et al. (2004) compared job, age, and life conditions with the causes and severity of occupational injuries among 880 male construction laborers. All had at least one occupational injury involving sick leave. For each injury, a questionnaire was completed by an occupational physician and the worker. The researchers found that worker risk was related to age, body mass index, hearing ability, and sporting activities (which could be a surrogate for physical fitness). Certain types of injuries were correlated with specific jobs. Data showed that the risk for falls and injuries from handling of objects or hand tools was similar for all construction workers, but the risk of injury from moving objects was highest for masons, plumbers, and electricians. Carpenters, roofers, and civil-engineering workers were most at risk for injury from construction machinery and devices. Being overweight was related to falls from the same or a lower level.

Other personal risk factors associated with construction falls and reported in the scientific literature include age, gender, strength, general health, fatigue, behaviors and attitudes, and (in many cases) training or job experience (Hsiao and Simeonov, 2001). Unfortunately, many of these factors can be directly related to each other (collinear) and may be sources of confounding, such as age, health, and experience. For example, as persons age, they are more likely to suffer from instability, which can lead to falls. Inherent in the aging process is a gradual decline in vision, physical strength, range of motion, and flexibility. Dong et al. (2012) found that older construction workers have a higher risk of fatal falls than younger workers, and that falls from roofs and ladders are a particular concern.

Visual performance is another personal factor that commonly decreases with age, which can increase the likelihood of a fall. For working at height, visual performance is related to elevation, changes in depth perception, and the ability to recognize potential hazards on the basis of training and experience (Hsiao and Simeonov, 2001). Simeonov et al. (2003) reported that standing postural instability is related to the effects of slope and elevation. Lastly, novice workers who lack training and experience may be more susceptible to falling because they are less familiar with the work environment and have less experience with maintaining balance in some conditions. Lack of worker training also may relate

to environmental factors involving leadership, management commitment, and corporate culture.

27.2.2 Falls from or through Ladders

Falls from ladders are the second leading cause of fall fatalities in construction. Most of the ladder-related injuries and fatalities that occur in construction involve the use of extension ladders or stepladders. Extension ladders have several connected telescopic lengths, come in four duty ratings, and are often between 32 and 72 ft long. Stepladders are hinged in the middle, form an inverted V when locked in place, and are typically shorter, ranging from 3 to 20 ft long.

A Swedish study showed that of 114 ladder accidents in 1 year, 73% involved extension ladders, 20% involved stepladders, and 7% involved fixed or stationary ladders (Bjornstig and Johnson, 1992). Falls from ladders in construction are often related to worker activities rather than ladder design; however, it is unclear how often best practices are used. Overreaching or slipping on the rungs is a common cause of ladder falls. Because of ladder safety concerns, some construction companies have implemented administrative controls through policies that discourage ladder use unless all other options have been exhausted.

Dennerlein et al. (2009) developed and tested an audit tool that assesses compliance with best practices for step- and extension ladder use in construction. The audit tool consists of checklists for ladder conditions (length, ratings, etc.), setup (proper angle, secure top, dry surface, etc.), and moving and working on a ladder (three points of contact, tied off, etc.). Individuals trained to use the tool scored a set of photographs and videos of ladder conditions, setups, and users working on them. The assessment tool has good agreement across users and provides a method to quantify ladder best practices and conduct safety evaluations.

Falls from extension ladders are caused by the ladder base slipping; the ladder tipping; the worker slipping while on the ladder or while transitioning from it to a surface at height; and failure of the ladder itself. Although engineering control measures are available, four actions are needed to advance ladder safety: research on visual indicators for setting up ladders at the proper angle; developing and evaluating methods to simplify moving from a ladder to a surface at height; integrating ladder safety accessories to ease carrying, assembly, and storage; and developing simple guidance for safe ladder use, maintenance, and inspection (Hsiao et al., 2008).

When setting up an extension ladder, the traditional approach involves grasping the rung in front with outstretched arms. NIOSH researchers have demonstrated a better method: grasping the side rails of the ladder instead of a step (Simeonov et al., 2012a; OSHA, 2013). This change provides a more natural placement of the outstretched hands and a safer ladder angle. NIOSH researchers (Simeonov et al., 2010) have also evaluated the use of electro-adhesion technology to help stabilize extension ladders at either end. Electro-adhesion technology uses electrostatic forces between surfaces, such as a wall and electro-adhesive pads on a ladder, to increase stability. A small battery pack provides power to each adhesive pad. A patent application has been submitted for using electro-adhesion technology with an extension ladder.

Simeonov developed a patented engineering solution to help extension ladder users position them at the proper angle. The indicator provides user feedback with visual, auditory, and vibration signals when the correct angle (75.5°) is reached (Simeonov et al., 2013). Without feedback, users tend to set up ladders at a shallower angle than needed. The NIOSH Ladder Safety Phone App has an angle-of-inclination indicator and is available

free of charge through the NIOSH website (<http://www.cdc.gov/niosh/topics/falls/>), the Apple App Store, and Google Play.

27.2.3 Falls from or through Roofs

Working on roofs is a high-risk activity that has resulted in serious workplace injuries and deaths from falls. Roofers and their employers need help to better manage and prevent falls from heights. Roof work is laborintensive, and it requires climbing and walking at different inclinations (Fredericks et al., 2005). Roofers install roofing materials and siding and work with sheet metal; their jobs also can involve inspections, repairs, cleaning, and other maintenance activities. It is important that the fall hazards associated with roofing are recognized and understood by all stakeholders.

Critical considerations for working safely on roofs include planning the work; being aware of fall hazards at various stages of the work; and using fall control measures, administrative controls, and PPE. Employers and workers should be able to identify the risks involved with roofs; choose proper access equipment for the job; understand and determine appropriate measures for risk control; and develop a plan to prevent falls during roof work.

Commercial and residential roofing are the two major roofing sectors. Commercial roofing typically involves low-pitched roofs that rise 4 in. per horizontal foot or less, whereas most residential buildings have steep-slope roofs that rise more than 4 in. per horizontal foot (Choi, 2007). According to NIOSH (2004), the rate of nonfatal work-related injuries was 1.1–1.8 times greater among roofers than among construction workers overall from 1992 to 2001. In addition, the rate of fatal work-related injuries was 1.6–2.8 times higher for roofers than for construction workers overall (Sa et al., 2009).

Falls from roofs depend on many factors, including the roof type or profile; roof slope and height; and duration and frequency of work. The potential fall hazards of roofing include falling over an unprotected edge; falling through a fragile or unstable roof surface (e.g., a skylight or rotted board); falling through openings on the roof; and slipping on roof surfaces, especially on pitched roofs. Falls can occur while accessing the roof, working on the roof, and transferring materials onto the roof.

Openings on roofs can also lead to fatal falls. Sometimes, the openings are created during work on roofs. Secured and marked rigid objects may be used to cover roof openings or fragile walking and working surfaces. The covers should support at least twice the maximum load and have full edge bearing on all sides. Falls through fragile roofs are problematic in both roof and building maintenance work, and cause half of the fatal falls. Fragile roof surfaces are areas that are not designed to bear loads. Persons standing on fragile and brittle roof surfaces are at risk if the roof gives way. These roofs are often made from molded or fabricated synthetic materials. The following are likely to be fragile: skylights (Figure 27.1), glass, fiberglass, polycarbonate roofing, old ceramic tiles, corroded metal roof sheets, and rotting wood.

Current measures to reduce falls from roofs focus mainly on fall protection, such as covers, guardrails, safety nets, and personal fall arrest systems, or the application of warning-line systems, safety monitoring systems, and fall protection plans. In many instances, these procedures are not practical for the industry, and current regulations allow the use of alternative means of fall protection, such as slide guards (Hsiao and Simeonov, 2001).

NIOSH has studied guardrail systems used to prevent falls through roofs (Bobick et al., 2010). Commercial edge-protection products were evaluated when used as perimeter guarding around a hole. Installations of the commercial products were compared



FIGURE 27.1
Skylight on a roof that had a fall through.



FIGURE 27.2
Construction workers using scaffolding on the side of a building.

with job-built guardrails made of 2×4 in lumber. The Occupational Safety and Health Administration (OSHA) requires that the top rail of a guardrail system be able to support 200 lb. Laboratory tests were developed using a 200 lb manikin, nine test subjects, and five guardrail configurations. All configurations met the 200 lb OSHA requirement. Bobick et al. found that the two edge-protection products can be used as perimeter guarding, and it highlights the importance of using proper materials and fasteners to construct guardrails. A follow-up laboratory study evaluated the strength of job-built guardrails made of lumber and nails (2×4 in and 16 penny nails). This work resulted in a patented guardrail system for use on roofs, stairs, and floors to prevent falls from holes or unguarded edges (Bobick and McKenzie, 2011).

27.2.4 Falls from and through Scaffolds

Scaffolds are temporary structures used to support workers and material during building repairs and construction (Figure 27.2). Scaffolds are typically built from metal pipes or tubes, horizontal boards, and couplers. Falls from scaffolds accounted for 21% of fatal construction falls reported from 1974 to 1978 (OSHA, 1979). Similarly, falls from scaffolds during 1980–1985 accounted for 17% of all fatal falls from elevations, second only to falls

from buildings (Bobick et al., 1990; NIOSH, 1991). The high rate of scaffold-related injuries caused OSHA to revise their scaffold safety standards in the late 1980s.

Suspended scaffolds were involved in 30% of the falls from scaffolds. Of the 25 falls from suspended scaffolds, 17 (68%) involved equipment failure. Personal fall protection equipment was used in only three of these incidents, but in each case it was not properly used. In one incident, a worker fell out of his improperly fastened safety belt. In the other two incidents, excessively long lanyards broke or separated after victims fell.

Halperin and McCann (2004) studied safe scaffolding practices at over 100 construction sites in the eastern United States and recommended improvements. A checklist was used to evaluate scaffold safety practices. Approximately 32% of the evaluated scaffolds were near collapse or were missing planks, guardrails, or adequate access. There was a strong correlation between structural problems and fall protection hazards. A correlation was shown among safe scaffold practices and competent persons with scaffold safety training, use of scaffold erection contractors, and scaffolds that were not simple frames. The authors recommended that construction firm managers outsource scaffolding assembly to specialized companies (many have lower accident rates) and that all scaffolding be checked prior to the start of work.

Yassin and Martonik (2004) conducted a similar study by evaluating regulatory changes from 1996 related to the design and assembly of scaffolding in the United States. The study examined the impact of those changes on the accident rate and failure to comply with standards. The study compared records for 5 years prior to the regulatory changes and for 4 years after passage. Although no distinctions were made related to the kind of scaffolding (suspended, mast climbing, or based on the ground), the study showed that the regulations produced a significant decrease in accident rates and the associated costs.

Falls from scaffolds are associated with a lack of compliance in scaffold design and construction as well as bodily action (Chi et al., 2005). Accidents involving temporary scaffolds represent a large percentage of construction injuries (Whitaker et al., 2003). Overexertion and fall injuries represent the largest categories of injuries to scaffold workers (Cutlip et al., 2002). The presence of guardrails or safety handrails on scaffolds could prevent slipping or falling if balance is lost; however, special training in maintaining postural balance at elevation is needed for inexperienced workers.

27.2.5 Falls from and through Telecommunication Towers

The number of telecommunication towers (Figure 27.3) in the United States has increased dramatically over the past 30 years. This increase has closely followed the greater use of cell phones, especially smartphones, and other wireless devices, and the demand they make, subsequently, for faster speeds and more data capacity. Similarly, more workers are needed to upgrade existing towers, which presents unique risks.

In 2013, 13 workers died after falling from telecommunication towers, and a similar number of fatal falls has continued into 2014. Some of the fatalities involved structural collapses. According to OSHA, a telecommunication tower worker has a 25–30 times greater risk of becoming a workplace fatality than the average US worker (Bukowski, 2014). Several of the 2013 fatalities involved workers who were not tied off or who had little or no experience climbing up to 200 ft to perform maintenance.

NIOSH reviewed BLS CFOI data from 1992 to 1998 and found 118 deaths associated with work on telecommunication towers. The fatalities included 93 falls, 18 telecommunication tower collapses, and four electrocutions (NIOSH, 2001). These incidents suggest that employers, workers, tower owners, manufacturers, and wireless service carriers may not



FIGURE 27.3
Construction worker using an aerial lifts near structural steel.

fully recognize the serious hazards associated with the construction and maintenance of telecommunication towers. Safe work practices should be followed, including the use of 100% fall protection (at all times).

Telecommunication towers are often manufactured in sections and constructed on-site by hoisting each section into place using cranes and bolting the sections together. Some smaller towers are self-erecting. Unfortunately, many of the older towers do not have embedded safety features such as permanent horizontal or vertical lifelines or anchor points to attach safety harnesses. NIOSH (2001) found the following factors in fatal falls from telecommunication towers: hoist failures, hoists not rated to hoist workers, truck-crane failures, inadequate fall protection, inadequate training, improper use of or incompatibility of lanyards, and worker fatigue. Although additional research is needed to fully understand how best to prevent these falls, some significant factors have been identified, including use of fall protection systems compatible with the tower being climbed, daily equipment inspections, and improved worker training on safe climbing and use of hoists.

27.3 Fall Solutions That Have Their Own Risks

27.3.1 Aerial Lifts

Ladder-related falls can be reduced through more frequent use of aerial lifts (Figure 27.4). Aerial lifts include vehicle-mounted “bucket trucks,” boom lifts, and scissor lifts. Scissor lifts are well suited for smooth finished floors in manufacturing. Rugged-terrain boom lifts are used on construction projects. When aerial lifts are extended, they can present stability issues, and they are complex systems that can fail because of mechanical issues or operator error.

Fall hazards associated with aerial lifts are well recognized (Burkart et al., 2004). McCann (2003) studied construction fatalities related to aerial lifts from 1992 to 1999. Of the 339 deaths reported in the BLS CFOI data, 42% involved boom lifts, 19% involved scissor lifts, and 7% involved other types of unapproved lifts. The main causes of lift-related deaths



FIGURE 27.4
Construction workers using several aerial lifts near structural steel.

were falls (36%) and collapses or tip-overs (29%), followed by electrocutions (21%). Most of the deaths were among electrical workers.

In a similar study, Pan et al. (2007) analyzed 306 fatalities related to aerial lifts (228 boom lifts and 78 scissor lifts) that occurred between 1992 and 2003. The researchers found that lift height and the vertical position of the worker correlated with fatalities. Tip-overs accounted for 44%–46% of boom lift falls and 56%–59% of scissor lift falls. Height accounted for 72% of the scissor lift fatalities in the BLS CFOI data. Falls, collapses, and tip-overs were involved in 83% of cases investigated by OSHA and the NIOSH Fatality Assessment and Control Evaluation (FACE) Program in all industries between 1990 and 2003.

Approximately 72% of scissor lift fatalities occurred in construction, yet the use of fall protection equipment on scissor lifts is not universally accepted as effective by safety experts. Pan and his colleagues showed that for a significant percentage of falls (82% per OSHA and NIOSH investigation data), existing fall protection systems were not used. NIOSH (Pan et al., 2012) conducted a laboratory study using a commercially available 19 ft electric scissor lift. Manikin drop tests were used to study fall arrest systems from a fully extended scissor lift. A computer model simulated movements, falls, and biomechanical impact. The study showed that fall arrest systems can provide effective fall protection on scissor lifts. However operators could suffer significant force to the lower neck during impact. When a fall arrest system is used on a lift, it must be anchored to the floor of the lift rather than to a railing (Harris et al., 2010).

27.3.2 Mast Climbing Work Platforms

A mast climbing work platform (MCWP) is a power-driven work scaffolding surface that climbs a vertical tower mast, allowing both work at height and the carrying of larger loads to higher elevations compared with traditional scaffolds. MCWPs are often used by masonry workers because they increase efficiency, save time, and are considered safer than traditional scaffolding. They potentially reduce the risk of musculoskeletal injuries to workers, because the platforms can be adjusted to an optimal height. The 22,000 MCWPs functioning in the United States are used by nearly 50,000 workers. When installed and used correctly, mast climbers are considered to be as safe as other scaffolds.

When they fail, however, deaths and serious injuries may occur, but the actual rate is not well documented.

Up to 80% of the MCWPs are anchored or tied to an adjacent structure. Even though they are considered to be safer than conventional scaffolding, from 2005 to 2007, MCWPs were involved in an average of three serious incidents, and multiple fatalities occurred each year. OSHA has documented 18 deaths and numerous serious injuries on MCWPs from 1990 to 2010 (CPWR, 2012). In addition, incidents involving near-misses, nonfatal injuries, and multiple fatalities have been recorded and investigated over the past decade. The greater loads that are possible on MCWPs can expose masons to falls and trips and increase the potential for collapse and falls. This risk is related to moving and carrying loads on unstable, confined platforms and the need to work using unbalanced postures.

CPWR established a diverse work group to examine problems associated with MCWPs and to discuss solutions to improve safety. The work group developed recommendations that have been directed to regulators and to persons or entities responsible for specifying and contracting construction work for mast climbers. A CPWR “white paper” indicated concern over the risk of fatalities (CPWR, 2010).

27.4 Fall Solutions Aimed at Prevention

27.4.1 Hierarchy of Controls

The traditional hierarchy of controls is widely used to eliminate or minimize occupational health hazards. The hierarchy includes, in preferential order, the use of (1) substitution or elimination, (2) engineering controls (such as local exhaust ventilation and process enclosure), (3) administrative controls (such as exposure limitations, training, and work practices), and (4) personal protective equipment (PPE) (such as respiratory protection and gloves).

To prevent falls in construction, a similar hierarchy should be followed. This hierarchy involves five levels, beginning with eliminating the risk by avoiding work at height where possible (Weisgerber and Wright, 1999). The five levels of the hierarchy of fall protection are outlined in Table 27.2.

27.4.2 Fall Protection Measures

In general, three types of conventional fall protection equipment are widely used in construction: guardrails, safety nets, and personal fall arrest systems (typically used as part of a comprehensive fall protection plan).

TABLE 27.2

The Five Levels of Hierarchy for Fall Protection in Construction

Level	Measure
1	Work on the ground or on a solid construction
2	Use a passive fall protection device (such as guardrails)
3	Use a work positioning system (such as fall restraints)
4	Use a fall injury prevention system (such as safety nets)
5	Work from ladders or implement administrative controls

Source: Adapted from Weisgerber, F. and Wright, M., *Elements of a Fall Safety through Design Program: Implementation of Safety and Health on Construction Sites*, Balkema, Rotterdam, 1999.

27.4.2.1 Personal Fall Arrest and Restraint Systems

Personal fall arrest systems (PFAs) are designed to protect a worker in the event of a fall (Figure 27.5), and fall restraint systems are designed to prevent a fall (Figure 27.6). PFAs consist of an anchor, connectors, a deceleration device, and a body harness. These systems stop a fall (OSHA, 1998) by preventing the worker from contacting a surface below through deceleration. PFAs must be inspected for wear damage and deterioration before each use.

Fall protection harnesses (Figure 27.7) are an integral part of PFAs; however, for many years, little was known about how well they fit workers. Early harnesses were designed based on parachute harnesses for men in the military rather than the more diverse construction populations, including women. At times, suspension trauma injuries after a fall have been attributed to poor harness fit. Hsiao et al. (2003) evaluated the fit of body harnesses for approximately 100 male and female construction workers. Their body sizes and shapes were measured with a laser scanner while they were suspended (with a harness) and standing (with and without a harness). Analysis determined that the current sizing selection scheme by height and weight was acceptable. However, redesign of harness components was needed for approximately 40% of those evaluated while standing or suspended. Fifteen body models for standard harnesses were identified.



FIGURE 27.5
Roofer using a fall arrest system.



FIGURE 27.6
Worker using a fall restraint system.



FIGURE 27.7
Worker wearing a body harness and fall arrest system.

Hsiao et al. (2007, 2009) evaluated harness sizing schemes and anthropometric data for workers. Three-dimensional torso scans and human–harness interfaces were evaluated for over 200 men and women. A model was developed and tested to classify over 96% of participants for best-fitting sizes. The authors recommended two sizes for women and three sizes for men over the current unisex system. The study suggested that thigh-strap angle and back D-ring locations could be used with static-fit testing to improve and reduce the risk of injury during a fall.

Fall protection for high steel and commercial construction is challenging, and workers are often forced to anchor at their feet. PFAs are designed to stop workers from free-fall. However, even after the PFA engages, the worker may continue to fall and could strike an object. The distance a worker falls includes the free-fall distance, the lifeline stretch from the force of the fall, and (if the worker uses a PFA or deceleration energy-absorbing device) the distance involved in absorbing shock. In its regulation (OSHA, 1998), OSHA limits free falls to 6 ft or less, and lifeline stretch and deceleration distance cannot exceed 3.5 ft. Therefore, a worker wearing a PFA system could fall up to 9.5 ft before stopping. Longer free-fall distances increase the chance of swing falls. Swing falls are especially hazardous, because the worker can hit an object or a lower level during the pendulum motion.

Fall restraint systems prevent workers from going over the unprotected edge of a walking or working surface by restricting movement (OSHA, 1998). They differ from PFA systems in that they consist of a body harness or belt attached to a tether, which is then attached to one or multiple anchor points (they do not include a deceleration device). Although these systems are not addressed by the OSHA Fall Protection Standards, some states require them. Guardrails are also a type of fall restraint system.

27.4.2.2 Guardrails and Slide Guards

Guardrails (Figure 27.8) are barriers to prevent employees from falling to lower levels (OSHA, 1998). They should be used when work is expected to take place at elevations of 6 ft (1.8 m) or higher. OSHA requires that guardrails be constructed from 2×4 in. lumber ranging from 39 to 45 in above the working surface. They are often mounted on the roof as joists or attached to the wall or roof of the building.

Slide guards consist of 2×6 in. or 2×8 in. pieces of lumber supported at the ends by metal brackets or lumber. They are intended to prevent workers from sliding down a roof



FIGURE 27.8
Guardrail system near the edge of a roof.

if they lose their balance. Slide guards were the primary means of fall protection in residential construction when the Interim Fall Protection Standards were in effect from 1996 to 2012. In 2012, OSHA rescinded the Interim Standards and required Subpart M, 29 CFR 1926 Section 500, which states that slide guards provide a minimum level of protection for certain roofing applications, but they primarily provide a means of precaution for specific limiting criteria. Therefore, slide guards may now be used with other fall protection techniques but cannot be used alone. More research is needed on their effectiveness.

27.4.2.3 Safety Nets

Safety net systems are placed under the work surface to prevent employees from contacting a lower level during a fall. OSHA regulates safety net systems to ensure safe and accurate performance of the net. When workers are at high elevations, the systems should be installed no more than 30 ft below the working surface and should have sufficient clearance to avoid contact with lower-level surfaces. Mesh sizes are limited to 6 by 6 in, and nets should be properly secured to prevent enlargement of mesh openings during a fall (OSHA, 1998).

27.5 Other Interventions

27.5.1 Training and Experience

In construction, falls from heights are more common among inexperienced workers. Studies have shown that well-developed safety training programs can be effective administrative controls to prevent falls (Kaskutas et al., 2009, 2010). In the US residential construction industry, employers often lack the specific safety knowledge to conduct adequate fall protection training. This problem can be more acute for small businesses, which often lack the significant resources and expertise of larger companies, and often results in higher injury rates (McVittie et al., 1997). Common sources for fall protection training include OSHA, insurers, unions, on-site mentors, and construction vendors.

Fall safety in the residential construction industry lags well behind that in the commercial and industrial sectors. Kaskutas et al. (2010) evaluated gaps in residential fall prevention training for apprentice carpenters. Trainers and researchers worked collaboratively to revise training and to fill the gaps. Evaluation and feedback from apprentices were used to improve the curriculum. Most apprentices worked at heights prior to training but did not commonly use fall protection. The revised training addressed safe ladder habits, truss setting, scaffold use, guarding floor openings, and using PFAs. New apprentices were targeted to ensure that training occurred before they began working. Hands-on experiences were emphasized in the training by using a fabricated residential construction site to practice fall protection. The revised curriculum was delivered consistently, and apprentice feedback was favorable. Needs assessment results were used to make further revisions, and researchers worked closely with the instructors to tailor the learning experiences. The researchers found that all these changes and adaptations made for positive results. Improving the quality of training and education in construction is important, and more work is needed to assess the impact of training efforts.

The analysis by Kaskutas et al. revealed two problems with formal safety training programs: (1) instructors are not always knowledgeable about application principles; and (2) safety training taught in class may be different from what is practiced on-site. According to study participants, these problems made them feel disengaged from safety training.

Fall prevention programs and equipment are necessary but are less effective without adequate training. Many Hispanic construction workers lack English proficiency (CPWR, 2008), which could impact their understanding of proper working procedures. Lipscomb et al. (2008) studied residential fall prevention through a series of focus groups with union apprentice carpenters at various levels of training. Their findings indicate that apprentices often do not apply safety principles they are taught to their work, a circumstance which illustrates how training alone can fall short. The findings also demonstrate the importance of measuring more than just knowledge when evaluating training effectiveness.

27.5.2 Prevention through Design

Prevention through design (PtD) is the concept of reducing occupational hazards by designing them out. PtD builds on the existing, traditional hierarchy of controls and moves it to a place earlier in the process. PtD is a viable intervention to improve worker safety that has gained momentum globally (Gambatese et al., 2005), but it has been slow to take root in the United States. In US construction, many barriers detract from its wider use, and design professionals have not embraced it as standard practice.

Many safety professionals feel that hazards are inadvertently “designed into” construction projects but could be eliminated with more focused PtD efforts. In fact, studies have shown a link between the PtD concept and a reduction in construction fatalities. Approximately 230 fatalities in NIOSH FACE reports were reviewed to determine whether they could be linked to the lack of PtD. The results showed that 42% of the fatalities could have been prevented if PtD had been used (Behm, 2005). For example, installing parapet walls or permanent guardrails on roofs can effectively prevent falls (NIOSH, 2014a).

The most important design issue identified was lack of embedded safety features. Behm, however, offered existing or new designs that could have prevented the fatalities. Embedded safety features on roof perimeters to aid in fall protection (NIOSH, 2014b) can include concrete straps, anchor points for use with appropriate PFA systems and lifelines, and guardrail supports. Another example is the use of prefabricated structures that are subsequently lifted into place rather than constructed at elevation. Design professionals

(i.e., architects and design engineers) are in decision-making positions and influence construction safety. It is easier to reduce hazards when safety is considered earlier in the project life cycle. This concept is in contrast to the common methods of planning for construction site safety, which occurs shortly before construction begins, when the ability to positively influence safety is limited.

Unfortunately, in the United States, there are few motivating forces (legal, economic, or regulatory) to encourage designers to adopt PtD. In traditional construction procurement, legal precedent precludes a designer from considering construction safety during the design process. Many design decisions are driven by the client's needs alone and a desire to reduce costs. The latter is based on a fallacious notion that increasing the safety of the workers will drive up construction costs. Construction contracts and the regulatory requirements of OSHA place the responsibility of worker safety on the construction firm or employer. For this reason, architects and design engineers often do not consider hazards during the design phase. In addition, they may be concerned about being responsible for future safety incidents, although it is unlikely that considering safety would put them at increased risk of legal liability. The lack of consideration of hazard prevention in the design phase also could relate to the common lack of training in construction safety and health early in their design and engineering education and careers. More research is needed in this area, but it is fairly clear that broader adoption and implementation of PtD principles could significantly reduce the risk of falls in construction.

27.5.2.1 Building Information Modeling (BIM)

There is significant interest in improving worker safety through safer design and the use of building information modeling (BIM) (Chi et al., 2012). BIM allows constructors to visually assess jobsite conditions and recognize hazards by using a virtual three-dimensional computer model during the design and engineering phases of construction (Azhar et al., 2012). BIM can allow the user to link construction management to safety-related activities. The use of BIM technologies can improve occupational safety by linking the safety issues more closely to construction planning; providing better site layout and safety plans; providing methods for managing and visualizing up-to-date plans and site status; and supporting safety communication, such as informing site staff about safety arrangements in response to a particular risk or warning. The use of BIM also encourages partners to conduct risk assessment and planning (Sulankivi et al., 2012).

Rajendran and Clarke (2011) outlined areas in which safety and health professionals can use BIM technologies: (1) designing for safety; (2) safety planning (job hazard analysis and pre-task planning); (3) worker safety training; (4) accident investigation; and (5) facility and maintenance phase safety. For these tasks, safety and health professionals can use three-dimensional renderings generated from the BIM models and walk-through animations. In addition, four-dimensional phasing simulations focused on the safety procedures can be generated to show how temporary safety elements and areas of concern transition during a project. A by-product of integrating safety with BIM is safety-related training videos, which help workers understand project conditions in a format that crosses language barriers (Azhar et al., 2012).

27.5.3 National Fall Prevention Campaign

A national campaign to prevent falls in construction began in April 2012 (NIOSH, 2013a). The campaign focuses on reducing the number and severity of falls from ladders, scaffolds,



FIGURE 27.9

Image used for the National Falls Prevention Campaign.

and roofs. The motto of the campaign is “Safety Pays, Falls Cost” (Figure 27.9). The campaign is co-sponsored by OSHA, NIOSH, and CPWR. The idea for the campaign originated from discussions among multiple stakeholders through the National Occupational Research Agenda (NORA) Construction Sector program, which is managed by NIOSH. Those stakeholders included internal NIOSH researchers and external organizations, such as universities, large and small businesses, worker organizations, professional societies, and other government agencies. The campaign is using a variety of strategies to reach the construction industry through the three-part message *Plan, Provide, and Train*: plan ahead to get the job done safely; provide the right equipment for workers; and train everyone to use the equipment safely.

Materials and resources are available on the campaign websites www.stopconstruction-falls.com, hosted by CPWR; <http://www.osha.gov/stopfalls/>; and <http://www.cdc.gov/niosh/construction/stopfalls.html>.

The first few years of the national campaign have been a success. Over 1 million people have been touched by it, and the research supporting the campaign received the prestigious 2012 Thoth Award from the Public Relations Society of America. An evaluation of the early months of the campaign indicated that information was not reaching small construction contractors, the primary target audience. Since then, reaching them has been a key focus. In 2013, the target of the campaign was expanded to preventing falls in all types of construction. Over 7000 construction employers and over two million construction employees have participated in some form of the campaign. Dozens of participants remain committed to this endeavor, and continued success is expected in the future.

The broad array of almost 70 campaign partners reflects the firm commitment of government, industry, labor, trade groups, and professional stakeholder organizations to end falls from heights, and so far the results are promising. The campaign is based on solid research analysis, organized by NIOSH and conducted by the NORA Construction Sector Council.

27.6 Discussion and Conclusions

Unlike others, the construction industry is difficult to study because of its complexity and the diversity of job tasks and employers, the prevalence of small companies, and variations in workforce skills, weather conditions, and work environments. Many construction

projects are characterized by temporary and transitory work. A typical construction workplace changes daily, and the type of work varies greatly, from new construction, repairs or renovations, and demolition to cleanup and reconstruction. One of the challenges inherent in construction is that the restructuring of work practices cannot be accomplished in individual workplaces or with individual workers. Turnover of workers is relatively high. Construction workers are employed by many contractors during their lifetimes, and industrywide changes are needed. Because the industry is so complex, this challenge will not be accomplished easily.

Why workers are injured and how physical hazards and behavior play a role are not well understood, partly because accident reporting details are not completely clear. Relatively simple hazard controls may prevent some injuries, however. Examples of such measures include perimeter protection for roofs and floor edges, correct ladder placement and anchorage, guarding of floor openings, housekeeping, inspection and maintenance of ladders, and proper scaffold erection.

Novice workers and those working for small companies are at greatest risk of fatal falls. Reasons for the greater risk in small companies may relate to a lack of resources for safety programs and personnel, owners' lack of knowledge of safety principles, the possibility that such companies are less likely to be inspected by government agencies, and their performance of inherently riskier work. As expected in a male-dominated industry, most victims are male. Older workers are represented disproportionately among fatalities, and declining physical and sensory capabilities likely play a role (Dong et al., 2012). Prevention measures are available to mitigate many of the falls. Although these are relatively simple, significant commercial and cultural barriers must be addressed to achieve broad acceptance and adoption of the measures.

The relationship of any particular variable with falls in many studies does not necessarily mean that its impact is great. However, it is helpful to summarize the major factors that minimize the risk of falls: dry, stable working surfaces; safety training with proper supervision and guidance; fall arrest systems and other PPE; a safety culture and climate; and worksite ergonomics. Other circumstances can have a negative effect on safety: poor weather, industry, and psychological issues; fatigue; and individual, organizational, and cultural factors.

Performing multidisciplinary research and addressing pertinent practices—involving engineering and design, education and training, behavioral and visual performance, and administrative issues—will offer the best chance of achieving meaningful, sustained results. Future fall prevention research should consider the main effects and interactions of the environmental, task-related, and personal factors that affect workers' balance. Improvements in the work environment, construction materials and methods, and work procedures and practices may improve safety and reduce falls (Hsiao and Simeonov, 2001; Hsiao et al., 2008).

Finally, the frequency of deaths and injuries related to roofs, scaffolds, and ladders should mandate dedicated efforts to develop intervention programs and evaluate their effectiveness. For example, incentive systems, work organization, and other managerial and organizational issues related to falls have not received significant attention and could be opportunities for study. Few studies have evaluated fall intervention programs in the real world. Although feasibility and study design require researchers to simplify this complex picture, the research should provide a holistic picture to evaluate interventions. A dynamic model for fall prevention is needed to provide feedback for construction stakeholders to aid in safety planning and fall prevention.

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