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Ladder Safety: Research, Control, and Practice

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ABSTRACT This chapter summarizes the causes, mechanisms, and risk factors for ladder falls and the range of available and most promising control and prevention strategies, with an emphasis on portable ladders. The focus is on proximal factors associated with the most common user–ladder interactions, discussed from the perspective of mechanics, biomechanics, and human factors. The chapter reviews the current ladder safety standards, regulations, and practices and summarizes the latest ladder safety research. The chapter includes suggestions for ladder design improvements, research needs, and measures for preventing falls from ladders.

15.1 Ladder Fall Injury Problem

Ladders are the most common equipment for access to elevation and are generally considered simple to use. However, ladders are also associated with considerable risk of injury both when used in the workplace and at home. Ladder-related injuries are persistent and yet represent a preventable public-health problem with a significant economic impact on society. The Consumer Product Safety Commission (CPSC) estimated that in 2013, approximately 511,000 people in the United States were injured in ladder-related incidents and were treated in hospital emergency rooms, doctors' offices, clinics, and other medical settings, and the financial cost of these injuries was \$24 billion, including work loss, medical, legal, liability, and pain and suffering expenses (CPSC, 2014).

Ladder fall injuries are a well-recognized problem in the U.S. workplace. In 2011, there were 113 fatal ladder fall injuries identified by the Census of Fatal Occupational Injuries; an estimated 15,460 nonfatal ladder fall injuries, involving at least one day away from work, were reported by employers to the Survey of Occupational Injuries and Illnesses; and approximately 34,000 ($\pm 6,800$) ladder fall injuries were treated in emergency departments, according to the National Electronic Injury Surveillance System—Occupational supplement (NEISS-Work) (Socias et al., 2014).

Successful prevention of ladder fall injury requires a comprehensive analysis of the mechanisms, causes, and risk factors for ladder falls, combined with a good understanding of ladder-user behavior and ladder mechanical performance during ladder–user interactions. Ladder mechanical performance is defined to a great extent by ladder type and characteristics.

15.2 Ladder Types, Classes, and Characteristics

15.2.1 Common Ladder Types

Various job types, and the associated work environments and tasks at elevated locations, impose physical size restrictions and support conditions requirements and thus define the need for different ladder types. The underlying desire to create a more versatile ladder has further resulted in a number of ladder designs with variable geometry. The American Ladder Institute (ALI) lists the following most common standard ladder types: stepladder, single ladder, articulated ladder, combination ladder, extension ladder, extension trestle ladder, job-made ladders, fixed ladders, mobile ladder stands, and ladder stand platforms (ALI, 2014a). Other ladder types include multipurpose, telescopic, sectional, folding, and rope ladders; and specialized ladder types such as library, escape, attic, dock, and orchard ladders (Ladders.net, 2014; Wikipedia, 2014).

15.2.2 Major Ladder Classification

Based on their purpose, design, structure, support conditions, and portability, all ladder types can be classified into the following three major classes: fixed, mobile, and portable. Fixed ladders are permanently attached to a structure or a vehicle and are used exclusively for access. Most fixed ladders are sufficiently strong to be used with an integrated fall-protection system, which can stop a user from falling in case of lost balance during climbing. Mobile ladders are used mainly as work platforms and require even and smooth floors to be moved from one location to another. They are heavy and have a large base of support, and thus they are generally very stable and safer to use. Portable ladders include all other ladder types that can be lifted and carried from one location to another, and they can be used for a variety of tasks, including for access and as work platforms. Because portable ladders are often improperly set up and misused, much of this chapter addresses matters of portable ladder safety.

15.2.3 Portable Ladder Classes

Portable ladders can be classified according to their structural geometry and their support conditions. Two major classes are *self-supporting* and *non-self-supporting*. In addition, some portable ladders can be attached and supported only at the top (e.g., escape ladders) and could be regarded as *suspended* ladders. The self-supporting ladders are usually A-shaped, have four legs, and can stand erect on their own as an independent structure (Figure 15.1). They include all stepladders, trestle ladders, and articulated and combination ladders. Some stepladders used in orchard agriculture may have only three legs. The non-self-supporting or leaning ladders require a structure to lean on and use as the upper support, and they rely on friction under their feet at the base to maintain stability (Figure 15.2). Non-self-supporting ladders include all extension ladders, straight or single ladders, telescopic ladders, sectional ladders, and combination ladders in their straight configuration. Since self-supporting and non-self-supporting ladders have different structures and mechanical behaviors and are associated with different causes and mechanisms of falls, they are treated and addressed in the chapter as two separate groups when required. For convenience, the self-supporting ladders are referred to as “stepladders,” and



FIGURE 15.1
Stepladder: self-supporting ladder.

the non-self-supporting ladders are referred to as “leaning ladders” as this term is more inclusive and self-explanatory.

15.2.4 Portable Ladder Characteristics (Load Ratings, Sizes, Materials)

Portable ladders are designed in different categories according the working load they have to sustain. The working load is the maximum applied load, including the weight of the user, materials, and tools that the ladder is to support for the intended use. According to the working load, portable ladders are available in the following five categories:

Type	Duty Rating	Working Load
IAA	Special duty	170 kg (375 lbs.)
IA	Industrial—extra heavy	159 kg (350 lbs.)
I	Industrial—heavy	114 kg (250 lbs.)
II	Commercial—medium	102 kg (225 lbs.)
III	Household—light	91 kg (200 lbs.)

The ladder duty rating determines the attributes of its structural components (e.g., rails’ and steps’ cross-sectional dimensions), its overall weight, its structural properties, and ultimately its mechanical behavior. The duty rating determines also the available sizes for a ladder.

Type	Available Stepladder Sizes
IAA	0.92 m (3 ft.)–6.10 m (20 ft.)
IA	0.92 m (3 ft.)–6.10 m (20 ft.)
I	0.92 m (3 ft.)–6.10 m (20 ft.)
II	Up to 3.66 m (12 ft.)
III	Up to 1.83 m (6 ft.)

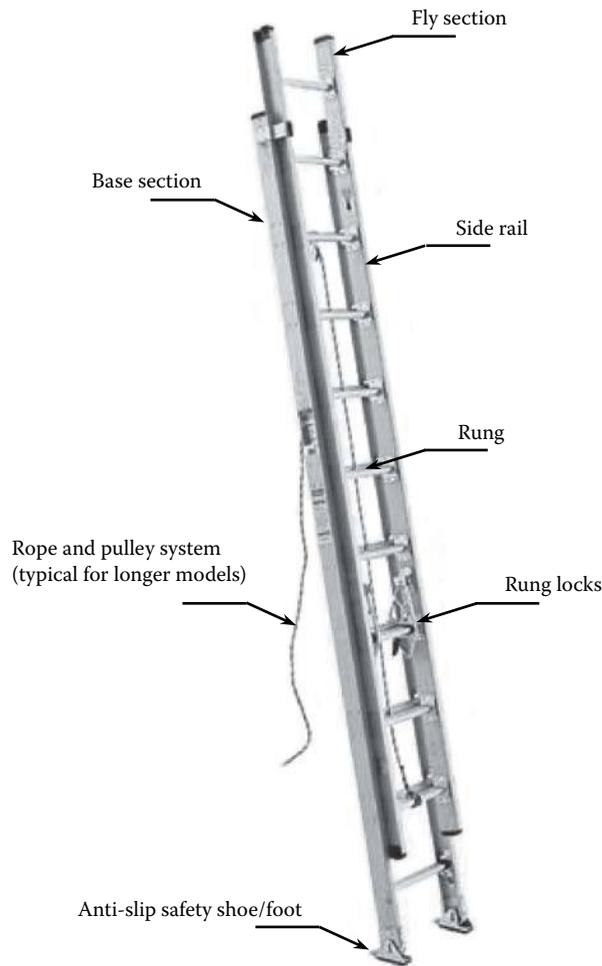


FIGURE 15.2
Extension ladder: non-self-supporting or leaning ladder.

Type	Available Extension Ladder Sizes
IA	Up to 18.30 m (60 ft.) (two-section) and 21.96 m (72 ft.) (three-section)
I	Up to 18.30 m (60 ft.) (two-section) and 21.96 m (72 ft.) (three-section)
II	Up to 14.64 m (48 ft.) (two-section) and 18.30 m (60 ft.) (three-section)
III	Up to 9.85 m (32 ft.) (two-section)

Ladders can be made of different structural materials, such as aluminum, fiberglass, or wood. A ladder’s composition and type are key considerations in selecting the right ladder for the tasks to be performed. For example, nonmetal ladders may be used safely around electrical lines or chemicals. Lightweight aluminum ladders are easier to use in jobs requiring frequent ladder relocation, adjustments, and manual transport. Only ladders with an industrial duty rating of Type IA or Type I can be used on construction job sites. A straight

ladder or extension ladder is best for reaching heights over 10 ft. Articulating ladders allow users to access elevated, difficult-to-reach areas.

A good knowledge of the available ladder types, their duty ratings, material properties, and geometrical characteristics, combined with a proper understanding of their function and most adequate areas of application, is required for proper ladder selection—improper ladder selection is often cited as a contributing factor in ladder fall injuries. Good safety practice requires that before using a ladder, the user should become familiar with the specific properties and safety rules available on the product data information labels and safety labels attached to the ladder.

15.3 Causes and Mechanisms of Ladder Falls

15.3.1 Theoretical Considerations

From the perspective of mechanics, biomechanics, and human factors, a fall can be defined as uncontrolled descent under the influence of gravity, and the causes of falls can be regarded as failures or disruptions in the control of dynamic postural stability during human interaction with the environment. Ladder-related falls can be broadly considered as resulting from failures or disruptions in the control of dynamic stability of the user-ladder system during its interaction with the environment. Some of the possible interactions include user with work surface, user with ladder, and ladder with support. During ladder use, the control of dynamic stability is most often compromised by internal forces generated by the user as self-induced perturbations. On some occasions, the disruption could also be caused by external forces (external perturbations), applied for example as an impact on the ladder or the user by a moving person, machine, or object. In most cases, ladder incident victims are not aware of the causes of their falls (Seluga et al. 2007). In order to develop a better understanding of the possible causes of ladder-related falls and to suggest effective preventive measures, a thorough analysis of ladder–user interactions is provided in this section.

15.3.2 Mechanical Behavior of Portable Ladders

Portable ladders are inherently unstable. The requirements for their portability set limits for their mass and geometry and thus define considerable limitations to their stability. Generally, the mass of the user is several times greater than that of the ladder, so the combined mass and the location of the center of mass (COM) of the ladder–user system will be greatly determined by the user mass and location on the ladder. Furthermore, during pushing or pulling tasks, the user can generate forces in any direction that can reach values equal to his weight. The limited ladder base of support (BOS) and the available friction at the ladder–support interface (between ladder feet and ground) is associated with severe limitations on the loading that a ladder can sustain while remaining stable. In general, for self-supporting ladders, the ladder will only remain stable if the projection of the user–ladder system’s COM remains within the ladder stability limits (within the boundaries of its BOS), defined by the positions of the supporting feet. For non-self-supporting ladders, in addition to this requirement, the required coefficient of friction (RCOF) at the base must remain below the available coefficient of friction (ACOF). The unstable nature of the

portable ladders requires vigilance and constant control, especially during their use, to maintain stability; this may be especially challenging while performing a task from the ladder, where the user’s attention needs to be carefully managed in a dual control task—between the control of work task and the ladder–user system stability control task.

Most portable ladders are supported at four points—typical step ladders have four legs, and leaning ladders have two rails supported both at the base and at the top. Since only three support points are statically required to support an object on a surface, all portable ladders are inherently over-constrained (Seluga et al. 2007). Previous stepladder testing has shown that even when all four ladder feet are positioned properly on the ground, only three legs/feet experience a significant ground reaction force at any particular instant, and that these “foot triplets” carrying the load periodically and abruptly change as the user moves on the ladder (Clift et al. 2002). Theoretically, up to four triplets are possible with four support points, and the loading may shift between them, depending on the shifts in the dynamic loading applied to the ladder and the resulting location of the user–ladder system’s COM (Figure 15.3). Structural rigidity affects the mechanical behavior of the ladder—more flexible configurations allow for more equal force distribution between the four support points and more gradual load transition between triplets. However, overly flexible ladder structures will be associated with excessive movement; therefore, the rigidity/flexibility of the ladder structure has to be optimized (Seluga et al. 2007). Three-point support and weight shifting between triplets is a condition that can create ladder and user instability and increase the risk of falls. While this issue has been well recognized for stepladders, it may be also a problem for straight and extension ladders, where a shift in the

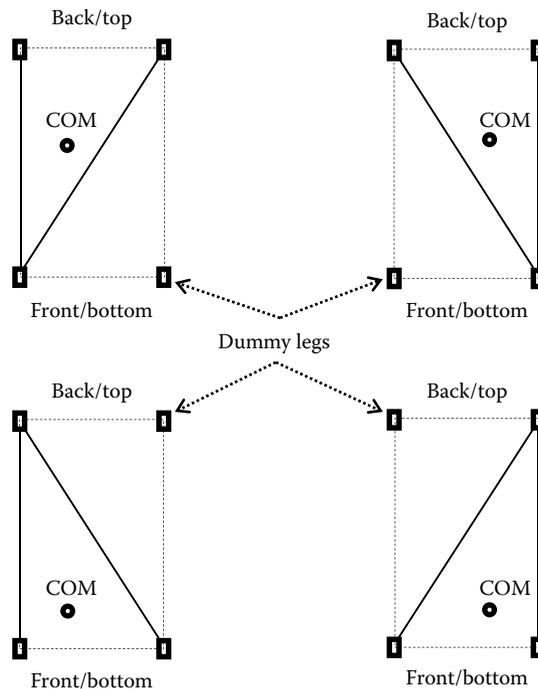


FIGURE 15.3 Four possible ladder base triplets as related to ladder-user center-of-mass (COM) location. “Front”–“Back” indicates a step ladder, and “Bottom”–“Top” indicates a leaning ladder.

reaction force between the two legs at the ladder base may lead to movement and increase the risk of slide-out events.

15.3.3 User–Ladder Indirect Interactions (Selection, Inspection, Positioning)

There are several phases that set the stage for the ladder–user interaction during ladder use: ladder selection, ladder inspection, and ladder setup. These three phases should be considered as indirect interactions, since the ladder is not loaded—the user has not climbed on the ladder and there is no risk of a fall. Furthermore, it is possible that the user is not directly involved in some or all of these phases—they may be performed, for example, by an employer or a coworker, or a neighbor in the case of home users. Such proxy indirect interaction indicates shared control, where the user relies on other parties for the proper performance of these stages. However, these interactions are crucial for the stability of the ladder and the user–ladder system. That is why it is advisable that the user always double check the proper performance of these steps to establish direct control. The following paragraphs provide information on the three phases.

15.3.3.1 Ladder Selection

The ladder selection process determines the ladder type, size, and rating and therefore the associated geometrical, structural, and mechanical characteristics of the ladder. The ladder has to accommodate the user's physical characteristics (weight) and also has to meet the requirements for the task(s) (weight of tool and materials, height and location of the job) in an optimal fashion. Therefore, proper ladder selection may substantially affect safety performance and the risk of falls. For example, the ladder type and geometric characteristics define its BOS and the associated stability limits; its rating, structure, and materials define its mechanical properties and load capacity; its effective height, as related to the task location, determines the need for reaching and thus affects the risk for tipping instability; and other characteristics, such as ladder feet and safety shoes, can also influence its sliding stability. However, very often the user does not have access to a wide selection of portable ladders or does not have the resources to purchase the appropriate ladder for the job and task at hand. In such cases, the user is frequently forced to make a compromise and use a suboptimal or inappropriate ladder, which can lead to excessive leaning and significantly increase the risk of a fall.

The ladder selection process may also include considerations related to the selection of different ladder accessories. Accessories attached to the ladder can also change its geometrical configuration and its mechanical behavior and as a result have profound effects on different aspects of its safety performance (Clift, 2004). More detailed discussion of different types of ladder accessories is available in Section 1.5.2.

15.3.3.2 Ladder Inspection, Care, and Maintenance

The ladder inspection phase and process is to ensure the ladder's structural integrity and proper operation before use. The ladder inspection should include the following steps: (1) inspect for damage or excessive wear the major structural components, such as rails, rungs, hinges, spreaders, and locks; (2) inspect for integrity and excessive wear the supporting components, such as rail top caps and safety shoes at the base; (3) inspect for proper operation all moving parts, such as hinges, spreaders, locks, pulleys, swivel safety

feet and shoes; inspect for cleanliness the rails, rungs, and safety shoes; and (4) inspect the integrity and readability of all safety labels. Thorough inspection of the ladders should be done periodically and before each use. Ladder inspection is directly related to ladder care and maintenance, which include the immediate cleaning of spills and drips, periodic oiling of the moving parts, replacing damaged or worn components and labels, and ensuring proper storage away from damaging weather effects and corrosive agents. Inspection, care, and maintenance should be regarded as critical control activities in the ladder–user interaction, since failures to provide proper care and maintenance and to thoroughly inspect a ladder before use may lead to ladder structural failure, loss of ladder stability, or loss of user stability.

15.3.3.3 Ladder Setup

During the ladder setup stage, the ladder is not loaded and the user establishes the ladder support conditions, its structural/geometrical configuration, and its proper space orientation. This stage is critical for the ladder's structural integrity, proper operation, and overall stability. The ladder setup process involves several steps.

The first step in the process is selection and preparation of the support surface. The support surface must be level, firm, even, and slip-resistant to ensure secure contact between the ladder legs and the ground. Most often the ground conditions are not perfect—sometimes the ground is not level and frequently not sufficiently firm; in such cases, other objects (a board, a brick, or a stone), available on the site, are used as wedges and levelers, which may create unsafe conditions. Leaning ladders' safety shoes are constructed so they can swivel and accommodate uneven surfaces, and they have riveted rubber foot pads to improve the frictional resistance and spur plate ends to secure the ladder base on soft support surfaces. More recent ladder designs and ladder attachments feature extendable legs specifically designed to serve as levelers on laterally sloped and uneven surfaces.

For leaning ladders, this step involves also the selection (and preparation) of the upper support surface so that both rails are in contact with the supporting structure. Some of the requirements for the ladder top supporting structure include adequate structural stability to sustain the loading from the ladder, structural rigidity to minimize the ladder movement, and sufficient frictional resistance to reduce the risk of ladder tipping sideways. Numerous extension ladder top accessories have been developed to accommodate various upper support conditions or protect from damage structural elements, such as windows and wall openings, corners, poles and trees, wires, and gutters. Inadequate selection and preparation of ladder support conditions directly affect ladder stability and may set the stage for a ladder fall or structural collapse.

The second step in the ladder setup process is to establish the ladder structural/geometrical configuration. For a stepladder, this involves spreading the two articulated ladder sections and securely engaging the spreaders on each side. For an extension ladder, this involves extending the ladder to the desired length and securely engaging the locks on each side rail. Incorrect or incomplete performance of this step may lead to structural failure and ladder collapse. Furthermore, for extension ladders, the proper ladder length should be estimated based on the elevated level of the task location, the last available/allowable rung (three rungs from the top) for support, and the conditions at the top supporting structure. For elevated transitioning tasks, the ladder length should allow sufficient extension (minimum 1 m or 3 ft.) above the structure edge to ensure safe hand grasping and support in the transitioning process (Figure 15.4).

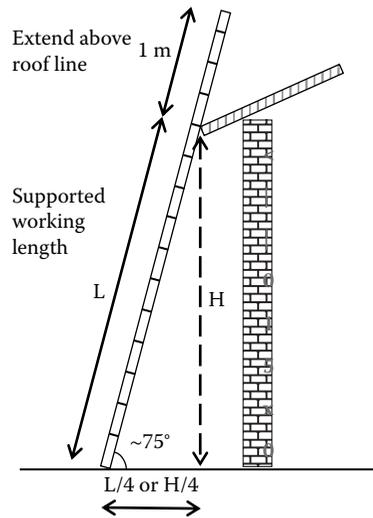


FIGURE 15.4
Setup of leaning ladders.

The last step in the ladder positioning process is its proper space orientation. The proper space orientation of a ladder requires considering the elevated location of the task and adjusting the ladder so that the user will normally be facing the location and will be able to complete the task without excessive reaching. For leaning ladders, this step involves also their proper angular positioning. The proper angular positioning of a leaning ladder is a critical step in establishing its stability, since it relies on friction at its base to maintain stability. The American National Standards Institute (ANSI) and Occupational Safety and Health Administration (OSHA) recommended angle for the positioning of extension ladders is approximately 75° from horizontal. This angle corresponds to a 4:1 ratio between the ladder supported-working length and its horizontal projection (Figure 15.4) (using the height instead the supported length in the ratio gives a similar result). Most ladder users are not familiar with this recommendation and generally tend to position ladders at sub-optimal angle, which may increase the risk of ladder slide-out incidents. Furthermore, often the proper ladder angular positioning may not be achievable due to obstructions and inadequate support conditions.

From the description of the ladder positioning process, it becomes clear that a major issue is the need for greater flexibility in the ladder structural geometry to properly accommodate the different surface geometries and various support conditions available in the environment. Some of the barriers to addressing this need include the associated increases in ladder mass, structural and functional complexity, and overall cost. Therefore, the need for flexibility in ladder structural geometry is being addressed mainly by different ladder accessories. However, these ladder accessories are not always available, and multiple accessories are needed for different support conditions. Furthermore, some ladder accessories may create additional problems when not properly installed and used.

An alternative solution to addressing issues with suboptimal ladder setup conditions is to secure the ladder to a supporting surface/structure by tying it off using available structural elements or custom tools, such as clamps, hooks, and spikes in the ground.

15.3.4 User–Ladder Direct Interactions (Ladder Use) and Major Ladder-Related Fall Mechanisms

Portable ladders are designed to provide quick and easy access to elevated workplaces and to serve as temporary support for various short-term tasks at elevation.

From the perspective of mechanics and biomechanics, *ladder use* is defined as the phase of direct ladder–user interaction—when on the ladder, the user applies dynamic loading to the ladder, while the ladder transfers the loading to the supporting surface(s)/structure(s). Furthermore, for most tasks, the user also interacts with one of the supporting structures (e.g., while mounting or dismounting the ladder) or with an independent structure (to complete a task), thus potentially generating considerable destabilizing forces. According to the “control paradigm,” failure or disruption in the control of these interactions may result in loss of stability (of the user or the system) and a fall. Different modes of failure and disruption in the control of dynamic stability during user–ladder interactions define the following three major types of ladder-related falls: loss of ladder (user–ladder system) stability, loss of user stability, and loss of ladder integrity or ladder structural failure.

Loss of user–ladder system stability occurs when the system’s COM vertical projection leaves its stability limits (the boundaries of its BOS), defined by the ladder’s four supporting legs. In addition, for leaning ladders, loss of stability may occur due to loss of traction as a slide-out event at the ladder base. For stepladders, most often the loss of stability occurs in the mode of tipping sideways and rarely by tipping forward or backward. In addition, twisting and racking movements can further destabilize the stepladder structure and lead to tipping or sliding at the base. For leaning ladders, loss of ladder stability can occur in four modes: ladder slides out at the base, top tips sideways, top tips backward, and ladder flips rotates alongside one of the rails (Clift, 2004). However, for leaning ladders, slide out is the most common stability failure mode, followed by top-tipping events.

To avoid a fall with the ladder, the user must maintain control over the stability of the whole system, in other words the user–ladder system, which uses the ground as support. To keep the whole user–ladder system in balance, the user must maintain control over the forces induced on the ladder at all time during different activities. However, the challenge for this control process is that the user does not receive feedback from the ladder about the proximity of the system’s COM to its stability limits (the boundaries of the BOS), or when the friction requirements (RCOF) are approaching the available friction (ACOF) at the ladder base. That is why some ladder users will intuitively do a test when they first step on the ladder by shaking it side-to-side to get a better feel of the available stability limits of the system; in other words, to test how much force can be safely applied in different directions. However, such a testing approach is inadequate because it is usually done at a safer stage of the ladder climbing, when the user is on the first several steps, while the most dangerous loading conditions are when the user is at the top of the ladder (Hepburn, 1958).

Loss of user stability can occur during activities such as climbing up or down or while using the ladder as support and performing a task. The loss of stability may be triggered by self-induced (internal) perturbations, such as slipping on a rung, tripping, misstepping, and losing hold or losing balance while standing on a step or a rung and performing a task; or by external perturbations such as being knocked down by an object, an instrument, or a machine.

To avoid a fall from a ladder, the user must maintain balance both while climbing and when using the ladder as support for a task. Using a ladder structure as support is challenging for a number of reasons—narrow rung surfaces associated with reduced BOS and stability limits; visual exposure to elevation; fatigue which can induce instability;

and unstable ladder structure used as support, which can move, shake, and twist under dynamic loading conditions. In addition to all these challenging environmental factors, while on the ladder, the user may perform various tasks, such as climbing, reaching, pulling/pushing, and using different tools, which may involve generation of dynamic forces that may perturb and disrupt balance control. To ensure user stability in these challenging conditions, safety regulations and best-practice recommendations suggest that the user has to maintain three-point contact at all time while climbing and working from the ladder. However, these recommendations may not always be practical. Furthermore, balance can also be disrupted due to deficiencies in user hand-grip strength or in available friction at the hand-rung or hand-rail interface, as well as at the shoe-sole and ladder step/rung interface.

Ladder structural failure may occur as a result of excessive loading (exceeding the prescribed design load) or due to a damaged or defective structural element, component or system. Examples include the failure of a side rail, step or rung, hinges, spreaders, or extension locks. Some ladder structural failures have been attributed to excessive ladder twist flexibility and the associated tear and distress (Seluga et al., 2007). Proper ladder selection, adequate inspection and maintenance, optimal positioning, and appropriate loading during ladder use are key measures to prevent ladder structural failures.

15.4 Risk Factors for Falls from Ladders

Most incidents, including ladder falls, are nonrandom events with multiple causes. The major causes and risk factors for ladder falls have been summarized and described in the technical literature (Cohen and Lin, 1991; Axelsson and Carter, 1995; Hsiao et al., 2008; Grant and Hinze, 2013) and in the ladder safety standards (ANSI, A14.2 2007). The risk factors have been categorized according to an ergonomic systems model in an attempt to look at the person–equipment–environment interface (Cohen and Lin 1991); and according to the most common ladder fall mechanisms (Hsiao et al., 2008).

Analyses have demonstrated that factors closest to the incident event (associated with ladder use and working conditions) are stronger predictors than variables further away from the event, namely individual characteristics (Cohen and Lin, 1991). Tables 15.1 and 15.2 represent an attempt to summarize and organize the major causes and risk factors for ladder-related falls associated with the main ladder–user interactions and fall mechanisms enlisted and discussed in Section 15.3.

It is important to recognize that the sources of information used to determine the causes for ladder falls come from circumstantial reports of ladder fall incident investigations and interviews with ladder fall injury victims using structured questionnaires. There is a lot of subjectivity and bias in this information, since it is based on ladder users' perceptions and recollections (Axelsson and Carter, 1995). In addition, most users have limited understanding of the mechanical performance and the failure mechanisms of ladders. Nevertheless, in the absence of more accurate evidence, this epidemiological information continues to serve as the basis for developing preventive measures.

To help avoid the conditions and circumstances associated with ladder fall incidents, organizations at different levels have proposed and developed sets of guidelines and ladder safety rules. The rule-based control approach may not be the best strategy to eliminate ladder fall incidents, but it remains the main focus of ladder fall injury prevention efforts.

TABLE 15.1

Risk Factors for Falls from Stepladders (Self-Supporting Ladders)

	Selection	Inspection	Setup			Use
			Support	Configuration	Orientation	
Ladder stability—tipping (accounting for 17.9% of cases, in Lombardi et al., 2011)	Improper size, type, or style; ladder is not the proper equipment	Missing, worn, spreaders	Soft, uneven, unstable, slippery surface, irregular surface firmness, surface slope, one or more feet unsupported, unstable or insufficient supports	Unlocked spreaders	Ladder not close enough to work location, incorrect stepladder placement	Standing above highest standing level, reaching out too far laterally, climbing onto ladder from above, handling heavy loads or unstable objects, applying side load, walking the stepladder
Ladder stability—sliding (15.4% of cases, in Lombardi et al., 2011)	Ladder is not the proper equipment	Missing, worn or contaminated feet	Uneven surface, unstable surface—ice, snow, or wet	Using a folded stepladder as a leaning ladder	Not close enough to work location, position parallel to the task	Reaching out too far, stepping off ladder, applying side load
User stability—slip, trip, loss of balance, struck by object, lost handgrip (55.2% of cases, in Lombardi et al. 2011)	Ladder is not the proper equipment	Worn, slippery, contaminated steps	Soft, uneven, unstable surface	Unlocked spreaders	Position close to uninsulated electrical wires	Electrical shock, mistepping, slipping, misstepping the final step while descending, standing on the top step of ladder; age, health, shoes
Ladder structure failure (3.2% of cases, in Lombardi et al. 2011)	Improper selection, ladder does not fit the loading	Worn, damaged or defective elements	Soft, uneven, unstable surface	Unlocked spreaders	Incorrect placement	Ladder is subjected to overloading

TABLE 15.2

Risk Factors for Falls from Leaning Ladders (Non-Self-Supporting Ladders)

	Selection	Inspection	Setup			Use
			Support	Configuration	Orientation	
Ladder stability—sliding outward at the base (Accounting for 40.0% of cases, in Lombardi et al., 2011)	Ladder too long or extending too far, ladder is not the proper equipment; improper selection of feet or slip-resistant bearing surfaces	Worn, missing or slippery feet	Unstable or insufficient supports; base—unstable, loose surface; low friction slippery surface—ice, snow, or wet; top—overextension above top support	Ladder not footed, ladder not tied off or blocked; extension locks not engaged	Leaning angle too shallow	Standing above highest standing level, careless climbing onto or off ladder (from or to a roof), applying side load
Ladder stability—lateral sliding at the top (6.6% of cases, in Lombardi et al. 2011)	Too short or too long (size); ladder is not the proper equipment	Worn or missing top end caps/covers	Base support—uneven unstable surface, irregular surface firmness; top support—uneven, slippery, unstable surface, (pole/tree, corner of building), ice, snow, or wet surface, insufficient top support	Not tied off, not held at base; feet unsupported or unstable; extension locks not engaged	Leaning angle too shallow; inadequate or excessive extension above the top support; not close enough to work location	Reaching out too far laterally; stepping on or off ladder to roof; applying side load
User stability—slip, trip, loss of balance, struck by object (34.7% of cases, in Lombardi et al. 2011)	Ladder is not the proper equipment	Worn, slippery, contaminated (dirty, oily, or icy) step surface	Uneven unstable surface, irregular surface firmness	Leaning angle not optimal	Leaning angle too steep (especially with flat rungs); position close to uninsulated electrical wires	Being struck by an object, or by electrical shock; excessive force, carrying objects, missteps while descending; age, health; shoes
Ladder structure failure (5.0% of cases, in Lombardi et al. 2011)	Improper selection, ladder does not fit the loading	Worn, damaged or defective structural elements	Soft, uneven, unstable surface	Extension locks not properly engaged	Suboptimal leaning angle;	Overloading

15.5 Current Measures to Control Falls from Ladders

15.5.1 Rule-Based Control

From the preceding analysis, it is clear that maintaining stability on ladders is not intuitive. To resolve the problem, a rule-based control strategy (also referred to as administrative controls) has been developed and implemented by organizations at different levels. Ladder safety standards, regulations and guidelines are rule-based control tools, which prescribe a set of rules for safe user–ladder interaction.

15.5.1.1 Ladder Safety Standards and Regulations

The OSHA, United States Department of Labor, develops, publishes and updates a standard (regulation) pertaining to ladders used in the construction industry. The portable ladder safety component resides in the OSHA Standards—29CFR Safety and Health Regulations for Construction subsection 1926.1053—Ladders (OSHA, 2014). The standard is based on information from the industry consensus standards and input from many stakeholders, including ladder user organizations. The provision for safe ladder use 1926.1053 (b) includes 22 rules addressing topics in the major user–ladder interaction categories.

The ANSI A14 Accredited Standard Committee develops, revises, and updates a number of industry consensus standards (*Ladders—Safety Requirements*), administered and published by the ALL. In addition to the technical requirement for manufacturing of ladders, the standards include a set of very detailed ladder-safety rules. The most essential safety rules are best summarized in the ANSI A14 Safety Labels developed for and attached to each ladder type. The current safety labels for stepladders include 25 safety rules and, for extension and straight ladders, 34 rules; furthermore, the rules are arranged in sections, which reflect the major user–ladder interactions: selection, inspection, setup, climbing and use, care, and storage.

In addition to the OSHA regulations and the ANSI standards, some ladder-safety practice guides have been developed by various organizations concerned with worker or public safety (Consumer Product Safety Commission [CPSC], 2011; Center to Protect Workers' Rights [CPWR], 2013; the Electronic Library of Construction Occupational Safety and Health [eLCOSH], 2014; the National Institute for Occupational Safety and Health [NIOSH], 2003; the National Safety Council [NSC], 2012; the American Academy of Orthopaedic Surgeons [AAOS], 2012). Most of these practice guides are based on the rules from the ladder-safety regulations and standards.

The following is a consolidated and simplified list of essential ladder-safety rules arranged by major user–ladder interactions.

Selection

1. Select ladder of proper size/length to reach working height.
2. Select ladder of proper duty rating to support the load of user plus materials and tools.
3. Select ladder of nonconductive material such as fiberglass or wood, if there is an electrical hazard.

Inspection

1. Inspect ladders before each use for broken, loose, missing, or inoperative parts.
2. Do not use damaged or worn ladders.
3. Keep ladders clean and free of slippery substances.

Proper Setup

1. Use ladders only on firm, level, and stable surfaces unless secured.
2. Do not use ladders on slippery surfaces without securing from movement.
3. For stepladders, set all four feet on the supporting surface.
4. For extension ladders, support both rails at top and base and tie off if possible.
5. Where tying off is not possible, use a second person to hold the ladder.
6. Do not let any ladder come in contact with electrical wires.
7. Keep clear the area around the top and bottom of ladders.
8. Secure ladder to prevent accidental displacement by work activities or traffic.
9. Do not set up and use ladder in high winds.
10. For stepladders, make sure the ladder is fully open and the spreaders secure.
11. For extension ladders, extend top section only from ground and make sure locks are secure.
12. Set extension ladder at 75° angle by using the ¼ length rule or the fireman's method.
13. Set extension ladder at least 1 m (3 ft.) above edge for roof access; tie top at support points.
14. Position ladder so that the user can face both ladder and task location.

Proper Climbing and Use

1. Always act carefully when climbing and using a ladder.
2. Never use ladders under the influence of alcohol, drugs, or medication or when in ill health.
3. Face the ladder and use both hands when climbing up or down.
4. Never climb a ladder from the side unless ladder is secured.
5. Grip and lean into ladder to maintain balance. Do not carry objects.
6. Keep the body's center of gravity between side rails. Do not overreach. Avoid pushing or pulling.
7. Keep ladder close to work location. Move ladder when needed.
8. Do not move, shift, or extend ladders while occupied.
9. Do not overload. Ladders are meant for one person only.
10. Use ladders only for the purpose they were designed.
11. Do not use ladder as brace, platform, or plank. Never use ladder on a scaffold.
12. For stepladders—do not climb, stand, or sit above second step from top of ladder.
13. For stepladders—do not use the rear section for climbing unless designed with steps.
14. For extension ladders—do not stand above third rung from top; never climb above top support.

Proper Transit and Storage

1. Properly secure and support ladder while in transit.
2. Store ladder where it is protected from foreign materials and corrosion damage.

15.5.1.2 Proper Use and Need for Education and Training

The proper use of portable ladders involves following closely all the requirements, recommendations, and guidelines listed in safety regulations and standards and practice guides. However, very often the ladder user is not familiar with some or most of the safety rules and recommendations. Furthermore, the average ladder user rarely reads the safety labels on the ladder. Occasionally, educated ladder users may find some of the safety rules impractical and thus ignore them. In most cases, users just follow their common sense to determine what is reasonable and may unknowingly use the ladder improperly.

For a rule-based control strategy to be effective, the users have to be educated and trained—the rule-based strategy is therefore a knowledge- and skills-based strategy. Numerous ladder-safety training courses and materials have been developed by different organizations, and some of them are available on the Internet. For example, ALI offers free access to its video-based training course (ALI, 2014b). More recently, training resources have become available as application for mobile devices—the NIOSH Ladder Safety app was released in 2013 and has been popular as a training tool among safety professionals and ladder users (NIOSH 2013).

15.5.1.3 Reasonably Foreseeable Misuse and Need for Further Design Improvements

Occasionally, educated users may be distracted and act under pressure to quickly complete a task without following the safety rules or take risks and knowingly compromise the conditions for safe use in order to complete a task. Frequently, knowingly or unknowingly, users buy ladders specifically to perform tasks that are considered unreasonable by the ladder industry. Some of these actions have been described as reasonably foreseeable misuse (Clift et al., 2002; Clift, 2004), and it has been argued that the ladder design should be improved to better accommodate users' expected behavior. Barriers such as requirements for simplicity, portability, low cost, and potentially increased manufacturer's liability prevent such improvements in ladder design. Therefore, some manufacturers have introduced ladder accessories to address these foreseeable misuses.

15.5.2 Design-Based Control (Human Factors and Ergonomics Considerations)

Integrating “safety-in-design” principles and solutions is the most efficient approach to reducing incidents and injuries associated with use of any product. Ladder-safety improvements can be achieved both through innovations in ladder structure design and in ladder accessories development.

The basic ladder design has remained relatively unchanged throughout history. The simple ladder geometry, defined by a set of side-rails connected with rungs or steps arranged at distances to allow comfortable climbing, effectively and efficiently fulfills its general function as a means of access to elevation. In the second half of the last century, with advancements in engineering materials and manufacturing technology, ladder structures have seen some significant improvements, resulting in lighter, stronger, and more durable ladder products.

While it is recognized that some improvement in ladder design may enhance its safety performance, further modifications in ladder design, beyond its basic function, have faced barriers. Some common sense ladder-design improvement needs include (1) increased stability through modified geometry, for example with wider base of support, adaptable legs/rails to accommodate various support conditions both at the bottom and at the top, and mechanisms for securing the ladder support points; (2) wider steps, providing secure standing support; and (3) handrails for improved stability during climbing and while standing and performing a task from the ladder.

Some of the barriers to incorporating the above-mentioned safety modifications into current ladder design include (1) increased ladder weight due to the additional structural components, which will compromise its portability and increase production costs; (2) increased base of support dimensions, which will limit the selection of appropriate support conditions; (3) increased structural complexity, which will increase production costs and increase the risk of system failure and thus the manufacturers' product liability; and (4) some safety improvements that may also increase user risk-taking behaviors.

Thus the existing need for ladder design modifications continues to be addressed by numerous ladder accessories. Thousands of patents and patent applications for ladder accessories have been published, and hundreds of products have been developed. Very few, however, have found a place in everyday practice. Some of these accessories have been manufactured without sufficient pretesting and standardization. To address this issue, the ANSI A14 committee recently developed and released the A14.8 standard for ladder accessories (ANSI, A14.8, 2013), which covers the most common accessory types and will gradually incorporate new classes of accessory products as they become available and established on the market.

This section provides some examples of ladder design modifications and accessories that address different ladder-safety issues.

15.5.2.1 Ladder Design Modifications and Improvements

The following are some examples of safety design improvements described in the research literature and implemented in products.

To reduce the risk of ladder slide-out incidents, some improvements have been made to portable ladder feet. Experiments by Pesonen and Hakkinen (1988) have shown that rubber-treated feet provide a better margin of safety than plastic or no treatment at all. Most extension ladders now have rubber-treated feet (Chang et al., 2005). In addition, most extension ladders have swiveling safety feet, incorporating a metal spike that can anchor the ladder base to prevent sliding on soft surfaces.

To improve the ease of climbing and reduce the risk of tripping, ladder geometry has been optimized to match the average ladder-user body dimensions and physical abilities. Investigators have speculated that a mismatch between ladder users' stature and ladder dimensions could contribute to incidents; very short or very tall persons could be more at risk than others (Dewar, 1977; Chaffin and Stobbe, 1979; Hammer and Schmalz, 1992). To address this issue, Chaffin and Stobbe (1979) evaluated the distance between ladder rungs and endorsed the ANSI recommendation of 30.5 cm (12 in).

To improve users' climbing comfort and reduce the risk of slipping, the simple round ladder rungs have been appropriately modified. The rungs of most extension ladders now are D-shaped with the flat upper surface at an angle of 75° to the rails. This design feature serves also as a guide for the user to a safe practice (Haakinen et al., 1988), since the rung becomes horizontal only when the ladder is positioned at the proper angle of 75°.

The following are some additional safety design modifications proposed recently in the research literature.

For stepladders, Seluga et al. (2007) suggested the following measures to control the risk of user losing balance: improve rigidity of stepladders to reduce twist flexibility and the risk of racking by making the front and rear side rails from tubular sections; redesign spreader bars to decrease twisting by using solid-plate or cross-shaped spreaders; and use a stiffer top cap for better stability and to resist twisting loads. To control the risk of falls from the top of stepladders, Clift and Navarro (2002) suggested that designs should not offer features permitting unsafe modes of use, such as top platforms on which one could step, and Shepherd et al. (2006) proposed removing the top step or ensuring that it cannot be stood upon and installing handholds and hand rails.

For extension ladders, Shepherd et al. (2006) proposed controlling the risk of electrocution by incorporating insulated segments; controlling the risk of slide out at the base by providing feedback for the ladder incline (e.g., by a bubble level or a hanging arrow) and methods to secure the ladder (e.g., by lashes, straps, or hooks that are fixed to the ladder); controlling the risk of user slipping by providing slip-resistant surfaces on rungs and providing barriers to prevent users from working off the side of the ladder; controlling the risk of falls during transition onto/off ladders by delineating the top 1 m of the ladder to help with proper above-edge extension during positioning and improving lateral stability by implementing splayed base.

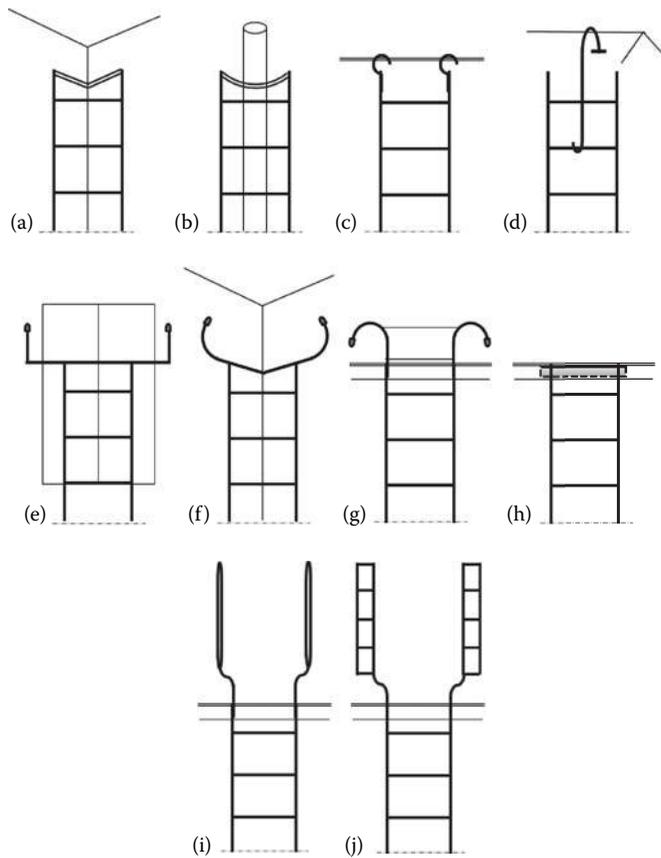
In addition to the ladder design suggestions in the research literature, thousands of ideas directed toward improving different safety aspects of portable ladders have been described in the patent literature. One interesting example is the “smart ladder,” designed with a tip-warning system that uses sensors to provide a feedback signal and warn the user of impending stability failure (Chandra, 2005). The majority of ideas relate to development of different ladder attachments and accessories rather than ladder-structure design modifications.

15.5.2.2 Ladder Accessories and Tools

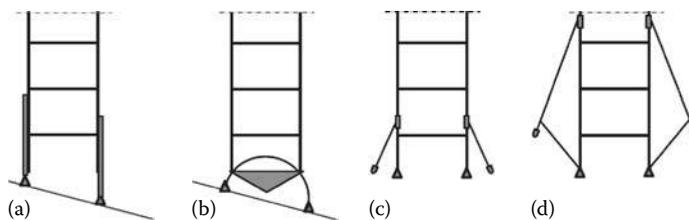
A ladder accessory, as defined by the ANSI A14.8 standard, is “a device which may be factory installed by a ladder manufacturer or field installed, and which may expand its function, utility and safety, but without which the portable ladder still functions in its intended manner.” The current standard recognizes three broad classes of accessories: top end (e.g., cable hooks, roof hooks, v-rungs, house pads, side rail end covers, pole chains/straps, stabilizers/stand-offs, walk-throughs) (Figure 15.5); bottom end (e.g., feet, spurs, levelers) (Figure 15.6); and miscellaneous (e.g., stabilizer straps, step brackets).

According to a study commissioned by the U.K. Department of Trade and Industry, in 1999 the U.K. market offered more than 80 accessories (safety devices) for extension (leaning) ladders (DTI, 1999). The study evaluation stage grouped the accessories into four major classes based on function and purpose and found that the “ladder stand-offs” offered some improvement in sideways slip resistance; most of the “levelers” reduced the risk of ladder base slide out; most of the “safety feet” offered some improvement in base-slip resistance; and most of the “stabilizers” offered some improvement in lateral stability at the top but not much in base-slip resistance.

A recent review on extension ladder safety (Hsiao et al., 2008) discussed some of the ladder safety accessories available on the U.S. market as they relate to the most common causes of falls and the associated risk factors. For example, accessories for reducing the risk of ladder slide out included inclination indicators, ladder base friction-enhancing devices,

**FIGURE 15.5**

Schematic diagrams of ladder top-end accessories: (a) V-rung; (b) tree/pole chain; (c) cable hooks; (d) roof/ridge hook; (e) stand-off stabilizer; (f) corner stand-off stabilizer; (g) stand-off gutter-protector stabilizer; (h) gutter-protector stabilizer; (i) walk-through with vertical hand-rails; (j) walk-through with horizontal hand-holds.

**FIGURE 15.6**

Schematic diagrams of ladder bottom-end accessories. (a) Adjustable-leg leveler; (b) circular leveler; (c) antislidestabilizer; (d) tripod stabilizer.

ropes and straps to secure the ladder base, and folding legs that engage in case of a slide. Accessories for reducing the risk of tipping sideways included hooks, straps, extender arms, and gutter stabilizers. While some accessories remain highly specialized (e.g., inclination indicators), many relate to more than one of the ladder-stability failure mechanisms (e.g., hooks, straps, gutter stabilizers).

Despite the multiple devices available on the market, few ladder accessories are being used in the field (Clift, 2004). Diversity of construction tasks and the time and effort required in carrying, assembling, and storing multiple accessories might hinder the wide use of these accessories. Furthermore, very few of these devices have been thoroughly evaluated. Systematic study of the effectiveness of ladder accessories and their possible integration with the ladder unit would be beneficial to ladder users (Hsiao et al., 2008).

The following evaluation criteria for leaning-ladder safety accessories have been suggested (Clift, 2004): a device would be considered to “enhance” safety if it increases the stability value in at least one of the four potential failure modes (slide out, side tip, back tip, or flip—see Section 1.3.4), while not causing the stability in the remaining modes to drop below the critical threshold. Furthermore, structural integrity under loading should be the primary safety concern for the device-augmented ladders, since many of the devices available on the market have been designed based on intuition rather than mechanics or engineering.

Engineering analysis demonstrates that most stability devices function by changing the ladder geometry and/or the available friction at the support points and, respectively, the direction and magnitude of the reaction force vector (Clift, 2004). In some instances, however, the changes in structural geometry may convert the leaning ladder–device system into a freestanding structure (a tripod) or a structure with multiple possible support points and stability states (defined by the possible triplets), which complicates the methodology for device effectiveness evaluation.

As long as the need for more adaptable and stable portable ladders is unmet, the development of ladder accessories will remain an important area in ladder safety. Thorough and adequate safety evaluation of the device-enhanced portable ladders may be complicated and may require significant efforts and resources. There is a need to further develop the classification, evaluation methodology, and standardization for ladder-safety devices and accessories. Developing and adopting robust criteria for inclusion of ladder accessories in the ladder-safety standards is an important step in this process.

15.5.3 Hazard Elimination and Substitution

The best strategy for preventing ladder fall incidents and injuries is to eliminate the need for work at elevation. Constructability analyses can be applied to identify tasks that can be finished on the ground. Furthermore, implementing safety-in-design principles may reduce the need for work at elevation, both in the short term during the construction process and in the long term during maintenance (Toole and Gambatese, 2008). If work at elevation cannot be eliminated, the next-best safety approach is to substitute the use of portable ladders with safer equipment for work at elevation, such as aerial lifts, rolling scaffolds, or mast-climbing scaffolds. While the substitution approach becomes more and more popular among large construction companies, it may be still infeasible for smaller construction and maintenance companies and homeowners.

15.5.4 Fall Protection Measures

The current OSHA regulations do not require fall protection for ladder use; however, using some fall-protection measures for work on ladders may be feasible under certain circumstances, such as availability of adequate and easily accessible anchor points. Securing the ladder and using a fall-protection system would be advisable especially when performing strenuous activities from the ladder such as pulling and pushing.

Fall-protection measures are directed and designed to reduce the dangerous consequences of a fall after it has initiated, in other words, to reduce the risk of impact injury by controlled transfer of the kinetic energy of the falling body to a supporting structure. The most common fall-protection measure is a fall-arrest system, which involves the use of a full body harness attached with a lanyard to an anchor point on a supporting structure. The fall protection harnesses and lanyards are commercial products, designed to transfer safely the dynamic forces generated during deceleration of the human body. The critical element in a fall-arrest system remains the anchor point—it has to be designed and engineered or selected and approved by a certified professional for the specific work environment. In many circumstances, adequate anchor points are not available, especially in light construction, where the partially completed structures are not capable of supporting the fall arrest loads. Accessing safely any available anchor points may also be a challenge, which further limits the use of fall-arrest systems.

When adequate and easily accessible anchor points are available, using a retractable lanyard may be beneficial while climbing and working on ladders, since it allows movement while reducing the free-fall distance and thus the fall-arrest load that needs to be transferred. It should be noted that portable ladders are not designed to serve as an anchor point for fall-arrest systems even when secured at the top and the base.

Available alternative fall-protection systems include inflatable mats or foam mats that can be positioned on the ground around the ladder base. However, these are associated with severe limitations and have not been widely adopted. Innovative fall-protection solutions, such as wearable and automatically deployable airbag jackets, which may be particularly appropriate for use on ladders, are not fully commercialized yet.

15.6 Recent Ladder Safety Research

15.6.1 Improving Extension Ladder Setup

A leading cause for extension-ladder fall incidents is a slide-out event usually related to suboptimal ladder inclination. An improved ladder positioning method or procedure could reduce the risk of ladder stability failure and the related fall injury. Recent studies conducted at the NIOSH laboratories compared the accuracy and efficiency of different anthropometric and instrumental methods to achieve optimal ladder angular positioning.

15.6.1.1 Anthropometric Methods Evaluation

The objective of the first study (Simeonov et al., 2012) was to evaluate the effectiveness of two anthropometric positioning methods: the ANSI A14 standard label (Figure 15.7) method (“stand-and-reach to hold the rung”) and the “fireman” method (“stand-and-reach to hold the rail”) (Figure 15.8). The results indicated that both anthropometric methods were similarly effective in improving extension ladder positioning; however, they required 50% more time than did the no-instruction condition and had a 9.5% probability of setting the ladder at a less-than-70° angle. Shorter ladders were consistently positioned at shallower angles. The study concluded that, when accurately and correctly performed, anthropometric methods may lead to safer ladder positioning than does no instruction. Workers tended to underperform as compared with their theoretical anthropometric estimates. Specific training or use of an assistive device may be needed to improve ladder users’ performance.



FIGURE 15.7
ANSI A14 Standard anthropometric sticker.

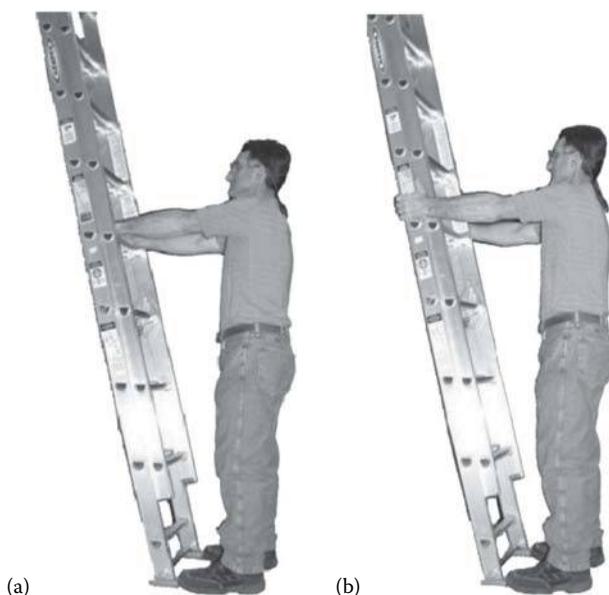


FIGURE 15.8

Two anthropometric methods for setting up leaning ladders: (a) ANSI A14 standard method; (b) fireman's method.

15.6.1.2 Instrumental Methods Evaluation

The second study (Simeonov et al., 2013) comparatively evaluated the effectiveness of a multimodal angle indicator, which provides direct feedback with visual and sound signals, with other existing methods for extension-ladder angular positioning, including the standard anthropometric method and a bubble-level indicator. The results indicated that the bubble-level method was very accurate but required more than double the time of the no-instruction method. The multimodal indicator improved the ladder angle setting as compared to the no-instruction and anthropometry methods and required the least time for ladder positioning among all tested methods. The main advantage of the new multimodal method is that it provides continuous feedback on the angle and hence does not require repositioning of the ladder. Such an indicator can be a valuable tool for training ladder users to correctly apply the current ANSI A14 standard anthropometric method in ladder angular positioning. The multimodal indicator concept has been extended to become a hand-held tool in the form of a smartphone application (see Section 15.6.2).

15.6.2 Innovative Mobile Technology Tools: The NIOSH Ladder Safety App

NIOSH recently released its first smartphone application, which is aimed at improving extension-ladder safety (Figure 15.9). The Ladder Safety phone app features an angle-of-inclination indicator that uses visual, sound, and vibration signals, making it easier for workers and other users to set an extension ladder at the proper angle of 75°. The app also includes a "Selection" tool which provides an interactive and easy-to-use procedure to select the minimum required ladder duty rating corresponding to the user characteristics and task. Furthermore, the app features an "Inspection" tool, which provides a comprehensive, graphic-based, interactive, and easy-to-use checklist for ladder mechanical



FIGURE 15.9
The NIOSH Ladder Safety smartphone app.

inspection. The app's "Proper Use" tool presents a set of standard-recommended rules in a clear graphic format, which is both informative and easy to understand.

Using smartphone technology, the Ladder Safety app delivers free and easy-to-use ladder safety tools and information, reference materials, and training resources into the hands of individual ladder users wherever and when they are needed. NIOSH developed the app using, patented technology, innovative research, existing information from safety regulations and consensus standards, and input from industry. The application is available in English and Spanish as a free download for Apple iPhone/iPad and Google Android devices. Recently, the application has been updated to include stepladder safety. Additional information on the app is available at the NIOSH webpage on Prevention of Fall Injury: <http://www.cdc.gov/niosh/topics/falls/mobileapp.html>.

15.6.3 Enhancing User Stability on Extension Ladders: Hand-Grip Issues and Three-Point Control

The ability to break a fall due to a slip or loss of balance on the ladder by grasping and holding onto the ladder may be a critical control mechanism to reduce the risk of ladder fall incidents. It has been previously reported that most people prefer holding the ladder side rail while ascending or descending on a portable ladder (Irvine and Vejvoda, 1977). Most likely, this preference is due to the convenience of being able to slide the hand on the ladder side rail for continuous lateral control. Since vertical support and climbing is exclusively done with the legs, the hands are used mostly for sideways balance (Barnet and Poczynok, 2000). However, the importance of a correct holding strategy becomes evident in case of a lost footing, when a good grasp on a handhold becomes critical to break a fall (Barnet and Poczynok, 2000).

The most important feature for control when exposed to a fall hazard is being able to hold onto a properly positioned and designed handhold during a loss of balance so that one's grab hand prevents the fall without slipping off (Ellis, 2012). Holding side rails or vertically placed holds provides a hand grip based on friction, while holding a rung or horizontal bar is referred to as horizontal power grip (Barnet and Poczynok, 2000). A recent biomechanics study found that holding a horizontal round object or grab bar (similar to a rung) with a horizontal power grip provided a greater safety margin for

preventing a fall as compared to holding onto a vertical side rail or object when the fall starts (Young et al. 2012).

Based on these findings, Ellis (2012) recommended using a “three-point control” climbing strategy instead of the well-known “three-point contact” ladder-climbing safety rule. For portable leaning ladders, the three-point control strategy recommends that the user climbs by holding the rungs and should always use one hand and grasp a rung for stability. In an earlier discussion of this issue, Haakinen et al. (1988) pointed out that in practice, the dirt on the rungs results in the user trying to avoid touching them, and they suggested improving the design of the side rails to make the grip as steady and comfortable as possible.

15.6.4 Enhancing Step-Ladder Safety

Two of the major causes for falls from stepladders, addressed by recent research, are loss of balance on the part of the user and stepladder lateral tipping, usually related to excessive reaching. The following subsections discuss appropriate training and behavior modification strategies as well as compliance assessment tools.

15.6.4.1 Balance Control on Step Ladders

In a review of the literature related to human balance control on stepladders, Tichon et al. (2011) identified conditions that may degrade balance. Among the risk factors for losing balance on stepladders, they pointed out the reduced base of support on the narrow steps, the increased risk of compliant surfaces on excessively flexible ladders, and the absence of stepping strategies (due to a restricted support surface) or handhold restraining control strategies for the recovery of lost balance. To improve balance, they suggested that ladder users should avoid looking or reaching above their heads while working, wear thinner hard-soled shoes, and lean forward into the ladder to rest their shins against the step immediately above the step being stood on.

15.6.4.2 Lateral Reaching and the Belt-Buckle Rule

Guidelines for work on ladders recommend that the center of gravity of the user’s body should remain within the rails of the ladder (the “belly button” or the “belt buckle” rule). Research has indicated that novice ladder users might be expected to take fewer risks than more experienced ladder users and to increase their risk taking as experience increases. In an experimental study on lateral reaching from step ladders, DiDomenico et al. (2013) demonstrated that novice workers can acclimate very quickly to a challenging reaching task, especially when motivated to complete a task, resulting in dangerous overreaching, such as when the belly button (belt-buckle) is surpassing the rail. Ladder-specific safety training is recommended to continuously reinforce the emphasis that safety is more important than task completion speed.

15.6.4.3 Quantifying Best Practices in the Field

To assess the extent to which users comply with the best-practice guidelines for portable ladder use in construction industry, Dennerlein et al. (2009) developed and tested an audit tool using a hand-held computer. The auditing tool consisted of a series of checklists organized in four groups: ladder condition, ladder setup, moving on a ladder, and completing a task from a ladder. The results indicated that the tool is reliable and offers a practical method to quantify the best practices associated with ladder use.

15.7 Conclusions

Portable ladders remain the most common and widespread equipment for access to elevation, despite the increasing availability of alternative equipment for work at height, such as aerial lifts, rolling scaffolds, and mast-climbing scaffolds. They are the tool of choice in small construction and maintenance projects and for home use. Portable ladders are lightweight, affordable, and relatively simple devices; however, their use is associated with considerable risk of fall injury and thus a substantial burden on society.

Manufacturers have attempted to improve portable ladder design; however, most of the ladder-safety improvements are being introduced as accessories. Despite the perceived simplicity, the mechanical behavior of portable ladders is complex and difficult to model and assess, especially in the field. The current rule-based control strategies are not sufficiently effective. To reduce the burden of ladder fall injuries, there is a need for (1) further improvements in ladder design by integrating effective safety concepts and devices, combined with (2) continuous improvements in ladder-safety rules, and supported by (3) thorough ladder user training, and (4) rigorous field compliance assessment.

To prevent ladder falls, employers should consider the following steps: (1) Plan the work to reduce or eliminate the need for using ladders by applying safety-in-design and constructability principles to finish as much of the work as possible on the ground; (2) provide alternative, safer equipment for extended work at elevation, such as aerial lifts, supported scaffolds, or mast-climbing work platforms; (3) provide properly selected and thoroughly inspected ladders that are well-matched to employee weight, task, and location; (4) when applicable, provide proper accessories to supplement safe ladder use; and (5) provide adequate ladder-safety information and training for employees.

15.8 Disclaimers

The findings and conclusions in this report are those of the author and do not necessarily represent the views of NIOSH. Mention of any company or product does not constitute endorsement by NIOSH. In addition, citations to websites external to NIOSH do not constitute NIOSH endorsement of the sponsoring organizations or their programs or products. Furthermore, NIOSH is not responsible for the content of these websites. All web addresses referenced in this document were accessible as of the publication date.

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