

Extension-ladder safety: Solutions and knowledge gaps

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Abstract

Falls from ladders are the second leading cause for work-related fatalities in the US construction industry. A significant portion of these incidents occurs at building-construction-and-maintenance worksites during the use of extension ladders. This paper presents the results of a critical literature review related to: (1) risk factors associated with falls from extension ladders, (2) practical engineering solutions that may reduce fall-from-extension-ladder incidents, and (3) questions pertaining to ladder safety that remain unanswered. The review results show that the underlying causes of falls involving extension ladders include the ladder-base slipping out, ladders tipping, workers slipping while on ladders or transitioning from a ladder to a surface at height, and mechanical failures. Some engineering control measures are available in the literature; yet, significant knowledge gaps remain. The knowledge-gap analysis identified four actions needed to advance ladder-safety practice: (1) research on visual indicators to assist in setting up ladders at the correct angle, (2) developing and evaluating measures to ease the transition from a ladder to a surface at heights, (3) integrating ladder accessories into a convertible design to ease the carrying, assembling, and storing of multiple accessories, and thus to encourage safe practices, and (4) developing a graphic-oriented practical guide for safe ladder use, maintenance, and mechanical-flaw detection.

Relevance to industry

This paper identified knowledge gaps associated with extension-ladder use for advancing ladder-safety interventions. The development and evaluation of ladder-safety innovations will provide the necessary feedback to ladder manufacturers and ladder-standard-setting bodies for design enhancement and will provide workers practical solutions to reduce injury risks associated with extension-ladder use. Published by Elsevier B.V.

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1. Introduction

Ladders are one of the most widely used means of access to elevated surfaces; they are simple, quickly set up, and relatively inexpensive. But, there is a persistent safety hazard involved with ladder use as well. There were 133 fatal falls from ladders for the US labor force in 2004 (BLS, 2005). These incidents occurred in the construction industry more often than other industries. In addition, on average each year more than 164,000 emergency room-treated injuries occurred in the US relating to ladders (CPSC, 2004). While these injury data did not separate

occupational cases from non-occupational cases, it is reasonable to assume that a significant portion of these injuries occurred in the workplace. Similar fatality and injury incidents associated with ladder use occurred in other countries. In the UK, on average 13 people a year die at work falling from ladders and nearly 1200 suffer major injuries; these incidents accounted for more than a quarter of occupational falls in UK (HSE, 2007). Bradley (2007) reported a rate of 18.5 falls from ladders per 100,000 population requiring admission to hospital in Australia; a significant portion of these injuries occurred in the workplace or unspecified locations.

Many individuals may consider ladders as a simple device and may conjecture that ladder safety is a largely settled issue. However, the number of ladder-related

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injuries and fatalities prompted this systematic literature review to identify critical risk factors, and to determine what technologies are available and what needs to be done to reduce the unacceptable toll of human suffering and economic loss.

There are three major types of ladders: fixed ladders that are permanently attached to a structure or vehicle, free-standing step ladders, and extension ladders that are leaned against a structure. Fixed ladders are used almost exclusively for access; step ladders are most often used as temporary work platforms; and extension ladders serve a variety of purposes. This critical review focuses on fall injuries and technologies associated with the use of extension ladders.

1.1. Current regulations

In 1990, Occupational Safety and Health Administration (OSHA) published an updated standard pertaining to ladders used in the construction industry. The extension-ladder-safety component resides in the OSHA Standards—29CFR Safety and Health Regulations for Construction subsection 1926.1053—Ladders (OSHA, 2006) (Fig. 1). The regulations specified four key ladder-configuration rules and four key ladder-use rules.

1.1.1. Ladder-configuration rules

The ladder-configuration rules pertain to the design and manufacturing of ladders:

- Extension ladders must be able to support at least four times the maximum intended load.
- Each rung shall be capable of supporting a single concentrated load of at least 114 kg applied in the middle of the rung.
- Rungs must be parallel, level, and uniformly spaced between 25 and 35 cm apart.
- The minimum clear distance between side rails for all extension ladders shall be 29 cm.

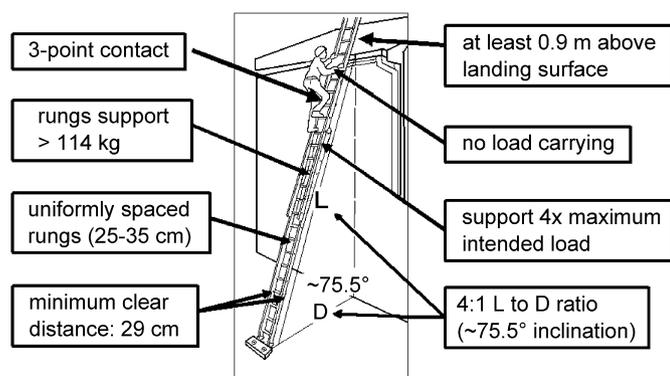


Fig. 1. The key elements of the OSHA Standards—29CFR Safety and Health Regulations for Construction subsection 1926.1053—Ladders.

1.1.2. Ladder-use rules

The ladder-use rules pertain to the set up and use of ladders:

- Extension ladders are to be positioned at such an angle that the horizontal distance from the top support to the foot of the ladder is about 1/4 the working length of the ladder.
- When extension ladders are used for access to an upper landing surface, the ladder side rails shall extend at least 0.9 m above the upper landing surface to which the ladder is used to gain access.
- Each employee shall use at least one hand to grasp the ladder when progressing up and/or down the ladder.
- An employee shall not carry any object or load that could cause the employee to lose balance and fall.

1.2. Current practice guidelines

In addition to the OSHA regulations, some ladder-safety practice guides have been suggested by various organizations that are concerned with worker or public safety (CPSC, 2004; CPWR, 2006; eLCOSH, 2006; NIOSH, 2006; National Safety Council, 2006). Some key points of these guidelines are described below.

- properly engage all locks;
- set up the ladder on level and firm ground; place large flat wooden boards braced under the ladder to level it on uneven or soft ground;
- do not place a ladder in front of a door that is not locked, blocked or guarded;
- keep your body centered between the rails of the ladder at all times; do not lean too far to the side while working;
- do not use a ladder for any purpose other than that for which it was intended;
- follow use-instruction labels;
- make sure no overhead obstructions and power lines are in the way;
- be sure that metal steps and rungs are grooved or roughened to prevent slipping;
- use the proper size ladder for the job; the average craftsman will generally work most comfortably at his/her shoulder level; when using extension ladders, the craftsman stands 0.9 m down from the top, which gives an effective working height of 0.6 m above the ladder top.
- always check a ladder before using it and never use a damaged ladder;
- never splice or tie two short ladders together to make a long section;
- extend an extension ladder only from the ground;
- never stand on the two top rungs of an extension ladder;
- always maintain 3-point contact and face the ladder when climbing it.

1.3. Current gaps in practice

While regulations and practice guidelines provide critical information for safe ladder uses, they are not designed to address all human–ladder–environment interface pitfalls under non-ideal conditions and therefore do not necessarily provide technical solutions to overcome safety obstacles (DTI, 1997). Some control measures are available in the literature to address the issue and some workers and safety professionals have used them. On the other hand, significant ladder-safety questions and gaps remain.

2. Objectives

The objectives of this critical review are to summarize: (1) key fall-injury risk factors related to extension-ladder use, (2) technologies for extension-ladder safety, and (3) questions pertaining to ladder safety and knowledge gaps that remain unanswered.

3. Method

Literature and product information from 1950 and after related to extension-ladder safety were located by searching the following computerized databases: safety-related journals available under ScienceDirect[®], American Society of Civil Engineers Online Journals, Applied Science & Technology, Civil Engineering Data Base, Medline, Lexis-Nexis, the US Bureau of Labor Statistics (BLS), the Electronic Library for Construction Safety and Health (eLCOSH), the OSHA, and the Internet. Input was also solicited from the American Ladder Institute (ALI), the International Ladder Manufacturers' Convention (ILMAC), a labor union, and two labor-management organizations in the US that represent large number of workers who frequently use ladders. Manual reviews of the journals where studies on this topic have typically been published were also performed. Papers identified in the initial search were screened using three criteria: (1) new data or a synthesis of a selected group of studies were presented; (2) studies concerned falls; and (3) study results dealt specifically with extension ladders or were applicable to extension-ladder safety. Only those reviews with substantial documentation were included; papers that were mainly based on the authors' opinion were excluded. Ladder-safety technologies from the Internet and trade associations were included in the review to accommodate the fact that limited information on the subject was available in professional journals. Original papers, as opposed to abstracts, were reviewed. Attention was given to three main topics: findings about suspected risk factors, findings about measures for reducing fall risk, and research gaps about ladder-fall prevention.

4. Results

The literature review identified 27 scientific manuscripts, five websites marketing ladder-safety products, and six

websites (organizations) providing ladder-safety tips with some engineering control suggestions. Seven of the manuscripts described epidemiologic studies that presented data on the magnitude of the problem and risk factors for ladder-related injuries, and 20 engineering studies examined the coefficient of friction (COF), ladder stability, and ladder-safety-related environment issues. These manuscripts met the minimum inclusion criteria although their quality varied somewhat.

4.1. Risk factors associated with falls from extension ladders

The most common causes of falls associated with the use of extension ladders can be organized into four major categories: slips of ladder base (Dewar, 1977; Hakkinen et al., 1988; Pesonen and Hakkinen, 1988; Shepherd et al., 2006), tipping of ladder top (Björnstig and Johnsson, 1992), persons tripped or slipped (Dewar, 1977), and ladder structure failure (Cohen and Lin, 1991a; OSHA, 1979; Tsipouras et al., 2001). The likelihood of a straight ladder-base slipping depends on several factors: angle of ladder inclination (Axelsson and Carter, 1995; Morse et al., 1999; OSHA, 1979; Partridge et al., 1998; Pesonen and Hakkinen, 1988), COF between the ladder base and the supporting surface (Cohen and Lin, 1991b; Pesonen and Hakkinen, 1988), magnitude of static and dynamic loads on the ladder (Pesonen and Hakkinen, 1988), the location of the load on the ladder (Pesonen and Hakkinen, 1988), and the COF between the top of the ladder and the supporting structure (Pesonen and Hakkinen, 1988). Ladder tipping is attributed to various factors, such as COF at the top of the ladder (Goldsmith, 1985; Pesonen and Hakkinen, 1988), workers overreaching (Cohen and Lin, 1991a; Partridge et al., 1998), difficult transition onto or off a ladder (Cohen and Lin, 1991a; Shepherd, 2000), and failure to secure the top of the ladder (Pesonen and Hakkinen, 1988). Workers tripping or slipping while using a ladder is associated with excessive force applied by the worker (Cohen and Lin, 1991a), carrying objects (Cohen and Lin, 1991a), being struck by an object (Cohen and Lin, 1991a), missteps (Axelsson and Carter 1995; Dewar, 1977; Hammer and Schmalz, 1992), slippery rungs (Björnstig and Johnsson, 1992), and worker age (Agnew and Suruda, 1993). Ladder structure failure may result from improper selection of ladders for tasks and poor equipment conditions (Goldsmith, 1985; OSHA, 1979).

4.2. Current measures to control falls from ladders

4.2.1. Controlling slips of ladder base

4.2.1.1. Angle of inclination. The required COF at a ladder base with a 65° inclined angle is on average 73% higher than the recommended optimal angle of 75° (Chang et al., 2005). However, many workers tend to set up extension ladders at too shallow of an angle (Chang and Chang, 2005; Hakkinen et al., 1988; Morse et al., 1999). The current standard work practices include a procedure

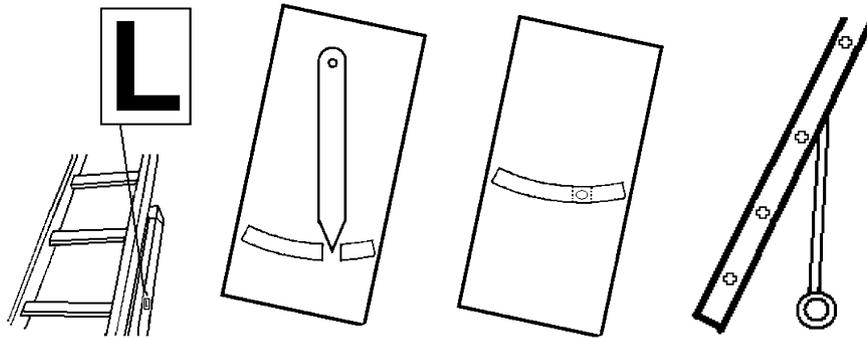


Fig. 2. Types of inclination indicators (L label, pendulum, bubble level, and roller) for assisting extension-ladder users to set up correct angle of inclination.

for safe ladder set up, the so-called firemen's method, in which the workers use their stretched arms to adjust the ladder inclination. However, the application of this method results in suboptimal inclination, with an average of 67° (Imbeau et al., 1998). Furthermore, this method does not take into account individual anthropometric differences and can lead to different results among workers. Some current ladders offer an "L" symbol on ladder rails to help workers set up an optimal angle, by placing the long hand of the "L" vertical to the ground level. However, aligning a symbol or determining the ladder angle in the field is not a straightforward task; studies have shown that the perceived slant of a terrain can easily be 20° off the correct angle of a slope (Proffitt et al., 2001), and these errors increase with load carrying and human fatigue (Proffitt, 2006). Some inclination indicator concepts can be found in the ladder-safety literature. They were developed to help workers set up an optimal angle (Fig. 2) (Goldsmith, 1985; Morse et al., 1999; Switalski and Barnett, 2003; Shepherd et al., 2006). Finding a low-cost inclination indicator that people will use and that can survive in work environments where ladders are used, may offer a solution to ease the ladder-base slip problem. Most manufacturers also offer leg extenders to allow the use of extension ladders on stairs, inclined surfaces, or uneven surfaces, and to reduce the potential for slips of the ladder base (Fig. 3).

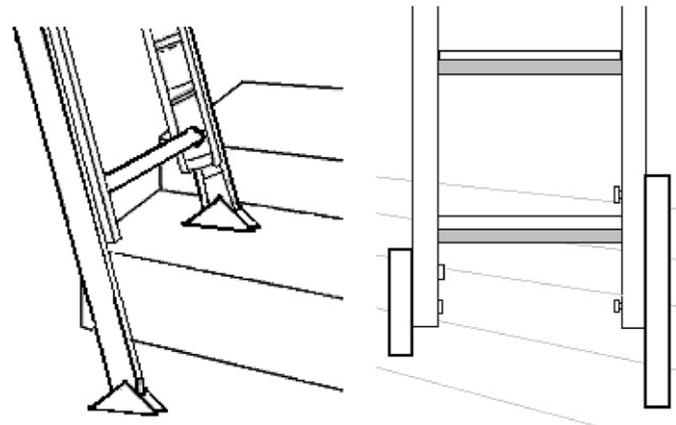


Fig. 3. Leg extenders to allow the use of extension ladders on stairs (left) and inclined surfaces (right) to reduce the potential of ladder-base slips.

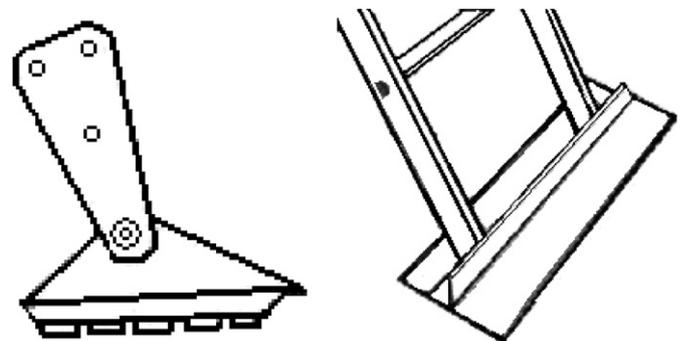


Fig. 4. Swivel-ladder foot with rubber sole (left) and ladder-base rubber pad (right) as measures to provide increased protection against slipping.

4.2.1.2. COF between ladder base and support surface.

Experiments by Pesonen and Hakkinen (1988) showed that rubber-treated feet provided a better margin of safety than did plastic or no treatment at all. Most extension ladders now have rubber-treated feet (Fig. 4) (Chang et al., 2005). In addition, some devices have been developed to improve ladder stability by improving ladder-base friction to resist slipping (Fig. 4) (Ladder Stopper, 2006). Some ladder manufacturers also offer ropes or straps as accessories for securing a ladder against slipping by tying the base to a secure object (e.g., a post) (Louisville Ladder Group, LLC, 2007; Werner Ladder, 2007). Other means to provide increased protection against slipping have been suggested in the literature, such as use of a fold-out leg hinged at the 3rd rung (Axelsson and Carter, 1995) and placing a weight

of no less than the ladder user to the base of ladder (Hepburn, 1958).

4.2.2. Controlling tipping of ladder

The problems of extension-ladders tipping are associated with inadequate COF at the top of the ladder, failure to secure the top of the ladder, and workers overreaching. Treatments for the tops of extension ladders are common to improve the frictional force providing lateral support (Fig. 5a) (Goldsmith, 1985).

In addition, extender arms (Fig. 5b) are available on the internet and in stores from most manufacturers to be used

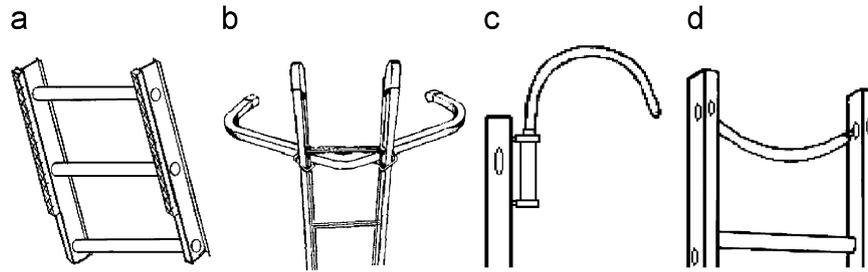


Fig. 5. Grooved ladder top treatments (a), extender arms (b), hooks (c), and straps (d) are being used for controlling tipping of ladders.

at the top of extension ladders to improve stability (Louisville Ladder Group. LLC, 2007). Hooks are also used to secure the top of extension ladders (Fig. 5c) (Werner Ladder, 2007; Stokes Ladders, 2007), and pole straps are used to secure ladders to poles (Fig. 5d) (Louisville Ladder Group. LLC, 2007). Also available on the internet is a ladder stabilizer marketed for sale that attaches to rain gutters and secures the ladder from tipping sideways or backwards (Ladder Station, LLC., 2006).

4.2.3. Controlling worker tripping and slipping

Although missteps are common causes of both fatal and non-fatal injuries, discussion of their underlying causes and prevention measures was limited to five studies in the current literature. Chaffin and Stobbe (1979) evaluated the distance between rungs and endorsed the American National Standards Institute (ANSI) recommendation of 12 in. Dewar (1977) suggested that a steeper inclination of a ladder caused users to rely more on their hands for balance and that this could contribute to workers slipping or stumbling. Investigators also 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 (Chaffin and Stobbe, 1979; Dewar, 1977; Hammer and Schmalz, 1992). Missteps when carrying material or when descending from the first rung to the ground are also common problems (Axelsson and Carter, 1995; Clift, 2004).

4.2.4. Controlling ladder structure failure

Mechanical failures lead to about 9% of ladder-fall injuries (Cohen and Lin, 1991b; Switalski and Barnett, 2003). If one assumes that these ladders were once sound and that they are not being used beyond their rated capacities, then it suggests that they are being weakened or damaged by use/abuse in the workplace (Clift, 2004). Regular inspection and maintenance are good practices to reduce the likelihood of ladder structure failure.

4.3. Ladder-safety questions and knowledge gaps remaining to be answered

4.3.1. Slip of ladder base

Studies on visual indicators designed to change users' behavior on ladder setup have yielded conflicting outcomes

on their effectiveness (Goldsmith, 1985; Morse et al., 1999); a systematic study on the subject, considering various low-cost indicators, training on the use of the indicators, and set-ups in the actual workplaces, would be desirable. Next, while means of enhancing ladder-base-slipping control have been suggested or marketed, none appears to have been systematically evaluated for feasibility (Clift, 2004); research that evaluates the effectiveness and feasibility of these approaches may contribute to improved ladder safety.

4.3.2. Tipping of ladder

Several engineering approaches, such as hooks, straps, extender arms, grooved ladder tops (Goldsmith, 1985), and ladder-gutter stabilizers (Ladder Station, LLC., 2006), to reduce tipping of extension ladders, have been marketed and are found in the literature. Clift (2004) cited a survey by Hitchcock and Stroud in 1988 that reported very few ladder accessories were being used. Diversity of construction tasks and the time and effort required in carrying, assembling, and storing multiple accessories might have hindered the wide use of these accessories. A systematic study of the effectiveness of these measures and their possible integration into a ladder unit would be beneficial to ladder users.

4.3.3. Worker tripping and slipping

Worker slipping or tripping on the steps/rungs of the ladder accounted for 10–34% of ladder-related incidents (Björnstig and Johnsson, 1992; Cohen and Lin, 1991a; Dewar, 1977; Partridge et al., 1998). Studies have suggested that these incidents may be associated with the angles at which the ladders were set up (Dewar, 1977; Hammer and Schmalz, 1992) or the spacing of the steps (Axelsson and Carter, 1995; Chaffin and Stobbe, 1979). Relying on a user's initiative to determine hazardous items, and hence appropriate safety intervention, is not a good practice (Clift, 2004); ergonomic studies aimed at improved angle, spacing, or step/rung design or set-up may be useful in reducing this class of ladder injuries. In addition, safety professionals understand that transitioning from a straight ladder to an elevated platform is a potentially hazardous process; in fact, 6% of occupational ladder falls involved transition to or from the ladder (Cohen and Lin, 1991a). Further studies on technologies to reduce the risk would be

desirable. Finally, the workers most commonly involved in ladder-related incidents are painters within the construction industry (Clift, 2004). A study to determine what painter tasks can be safely performed on a ladder would be valuable to workers and employers.

4.3.4. Structure failure

Studies have attributed 9% of the ladder incidents to structural failure (Cohen and Lin, 1991a; Tsipouras et al., 2001). Unfortunately, the specific types of failures and the role that ladder mechanical failures play in falls were not available. A study involving questioning of ladder-fall victims, to refine the available data on the above-mentioned issues, may shed light on reducing structure-failure cases. In addition, a field-based study to estimate the prevalence of extension ladders with known flaws, currently in use in the workplace, would further address the question.

4.3.5. Reducing the severity of fall injuries

While the above-mentioned fall-control measures can reduce ladder-related fall incidents, ladder users are still constantly exposed to fall hazards without additional protection. There is a need for novel supplemental fall protection measure or technology that can reduce the risk of severe injuries, should a worker fall. An inflatable fall protective airbag vest or materials that can absorb most of the impact energy in a fall incident would be beneficial to ladder users.

5. Summary

This paper presents risk factors associated with extension-ladder-related falls, current practices to reduce falls, and current technologies that may reduce falls from extension ladders. The information is useful as a practical compendium of source information for improving extension-ladder safety. The review also identified four critical knowledge gaps:

- Research is needed on visual indicators to assist in setting up ladders at the correct angle. Research efforts are suggested to study the effectiveness of current innovations by evaluating their engineering performance, user interface, cost, acceptability, and survivability in tough work environments.
- Developing and evaluating measures to ease the transition from a ladder to a surface at height is necessary.
- Diversity in construction tasks and the effort required in carrying, assembling, and storing multiple ladder accessories might have hindered the wide use of these accessories; integration of ladder accessories into a convertible design to support safe practices is needed.
- A graphic-oriented practical guide for safe ladder use, maintenance, and mechanical-flaw detection is needed.

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Disclaimer

The findings and conclusions are those of the authors and do not necessarily represent the views of NIOSH. Mention of any products does not constitute the endorsement of NIOSH.

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