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The effect of instructions on potential slide-out failures during portable extension ladder angular positioning

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ABSTRACT

Accidents involving portable ladders are a common cause of serious occupational and non-occupational injuries throughout the industrialized world. Many of these injuries could be prevented with better instruction on the proper usage of portable ladders. Research is reported that focused on both the human factors and engineering aspects of portable extension ladder usage based on common ladder setup procedures. Results of the human factors experiment revealed evidence of unsafe acts that could lead to catastrophic ladder slide-out accidents in real-life situations. Six different ladder setup methods were evaluated for safety and stability based on placement angles: the basic, 75 degree, stand–reach, L sticker, 4:1, and bubble level methods. Ideally, ladder users would set the ladder up at 75.5 degrees to achieve the consensus industry standard safest angle. Setup methods varied in complexity and nature of instruction. The level method produced the most accurate and the least variable results. The engineering analysis determined the coefficient of friction of a variety of clean and contaminated surfaces commonly used with ladders. This analysis determined the total number of slide-out failures that would likely have occurred in the data obtained in each of the ladder setup methods tested in the human factors experiment. Based on test participants' setup angles, the average calculated ladder slide-out failure rate was 8.7 percent for ladders positioned on a surface with the lowest measured coefficient of friction. When broken down by ladder setup method, the 4:1 method had a failure rate of 18.8 percent, the 75 degree method had a failure rate of 15.2 percent, and the basic method had a failure rate of 9.8 percent. The stand–reach and L sticker methods had identical failure rates at 3.3 percent and the level method was best at 1.1 percent. The level method provided the lowest error, least variability, and setup closest to the target angle of 75.5 degrees. Analysis of the overall results revealed the need for additional user training and clearer instructions affixed to ladders. This research is unique in that it combines an analysis and comparison of human factors and engineering in the same study.

Introduction

Ladders are a primary contributing factor to occupational injuries and deaths in the industrialized world. The U.S. Bureau of Labor Statistics (2008) reported 5214 fatal occupational injuries, with 700 of those attributable to falls and 119 related to falls from ladders of all types, including extension ladders. Ladders are commonly used by a wide variety of people from homeowners to handymen to heavy industrial contractors for a variety of applications and uses. However, if not used safely, ladders can be attributable to a wide range of injuries from minor bruises to permanent disabilities and even death. Ladders are typically either portable, such as stepladders and extension ladders, or permanently affixed to a structure. This paper focuses on portable extension ladders and the various effects of changes in ladder stability and resistance to sliding caused by setup angle and ground surface type and condition. Test results revealed that using an auxiliary safety device, such as a level, results in the safest ladder setup for users.

Ladder falls and accidents can be classified into three primary categories: physical failure of the ladder or its supporting surface, improper usage of the ladder, and improper ladder selection. Statistics from the Census of Fatal Occupational Injuries for 1992–1999 show falls as the leading cause of death in construction. Falls from ladders of all types during this period accounted for 14 percent of the total deaths related to falls (Burkhart et al., 2004). A study published by Creighton University (2003), based on statistics from the Occupational Safety and Health Administration and the Bureau of Labor Statistics, revealed more than 15 percent of all worker compensation cases are related to ladder accidents. The number of

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ladder related injuries in the United States increased by more than 50 percent from 1990 to 2005 with more than 2.1 million people being treated in hospital emergency rooms during the same period. Approximately 10 percent of those injured required hospitalization (Preidt, 2007). According to the United States Consumer Products Safety Commission there were 164,000 emergency room visits related to falls from ladders of all types in 2004, an average of 449 injuries per day (Berendsohn, 2005).

The setup angle of a ladder is defined as the angle of the ladder relative to the horizontal. In general, the lower the setup angle the more likely the base of the ladder will slip out and cause the ladder to fall. The recommended ideal setup angle for extension ladders is 75.5 degrees relative to a level surface (ANSI A14.2). This is readily achieved by setting the base of the ladder a distance from the wall equal to one fourth the working length of the ladder. The working length of the ladder is measured from the base, along the side rails, to the point of support at the top. A literature review by Hsiao et al. (2008) identified several factors affecting the likelihood of a ladder slideout failure including ladder angle, coefficient of friction, as well as type, location, and magnitude of the load.

The resistance to sliding of the base of a ladder on a clean, dry surface is a function of the static coefficient of friction, which is dependent on surface roughness. The static coefficient of friction is the ratio of the lateral force required to move an object relative to its weight. The surface must be clean and dry to ensure that the measurement of the force required to move the object is a true static coefficient of friction. For surfaces contaminated with moisture or foreign debris, the coefficient of friction becomes a slip resistance index because the ratio of the force required to move an object relative to its weight is altered due to the presence of contaminants on the surface (English, 2003). For the remainder of this paper, coefficient of friction will refer to both uncontaminated and contaminated surfaces for simplicity. After the ladder begins to slide, the static coefficient of friction becomes a dynamic coefficient of friction. The corresponding dynamic value is approximately 25 percent less than the static value, although this relationship may vary greatly for various surfaces (Beer and Johnston, 1976). All values addressed in this paper, both the coefficient of friction and the slip index, are considered to be static values because the ladder and its associated forces will be analyzed in a stable, non-moving condition. However, the effects of dynamic loading of the ladder as one climbs will be considered in the final analysis as it relates to slide-out failures.

Previous research revealed accidents caused by ladder slide-out at the base are one of the most common causes of ladder injuries. Dewar (1977) found that out of 248 accident reports involving ladders, 66 percent of the accidents occurred when the base of the ladder slipped, either with participants climbing or working on the ladder. He also reported that many ladders were commonly used at angles shallower than the recommended 75.5 degree angle, possibly because of a feeling of insecurity at the steeper angle related to the potential to fall backwards (tipping failure). Further investigation of these conditions was one of the goals of the present research. Friction requirements related to climbing conditions for portable extension ladders were investigated by Chang et al. (2004). They found that the angle of inclination of the ladder and the climbing speed were the two most important factors for stability, with many ladder accidents being the direct result of improper setup and sliding at the base. One of the more detailed studies took into account not only the setup angle of ladders but also the coefficient of friction at the base of the ladder (Häkkinen et al., 1988). Similarly, they found that the most frequently reported mechanism for ladder accidents was sliding of the base of the ladder.

This study was performed to fully evaluate the most widely used ladder setup methods and to determine the method that resulted in a setup angle closest to the target angle of 75.5 degrees. Previous studies either evaluated the various setup methods, causes of failures, or results based on coefficient of friction, but not all of these factors collectively. This study combined the results of failures based on method (human factors) and coefficient of friction (engineering). Results were analyzed to determine the setup method that should minimize and substantially eliminate slide-out failures for users. The level method was hypothesized to yield the safest results for users.

Human factors

A detailed study evaluating the human factors of ladders related to setup angles was performed by Young and Wogalter (2000). Of their sixty eight participants, five reported being previously injured while using a ladder and 34 others knew someone who had been injured. The participants were instructed to position a ladder using six methods to achieve the recommended setup angle of 75.5 degrees. These included estimating the angle without aids or assistance, use of the 4:1 rule (length to base ratio), use of a bubble level, application of the stand–reach method, or use of the L sticker method. The ‘L’ sticker is a symbol located on the side of some ladders shaped like an ‘L’ that provides a visual aid to proper setup angle by aligning the vertical part of the ‘L’ with a wall or vertical surface and aligning the bottom of the ‘L’ with the ground. The stand–reach method consists of one placing their toes at the base of the ladder and extending the arms and hands straight out with palms touching or holding the ladder rung.

Participants were evaluated on their ability to achieve an approximate setup angle of 75.5 degrees with a 20 ft aluminum portable extension ladder. The results revealed the shallowest angles were produced by the basic condition followed by the stand–reach, L sticker, and 75 degree approximation condition; these angles ranged from 66.9 to 71.0 degrees. The 4:1 method resulted in a steeper angle of 73.4 degrees and the bubble level method was steepest and most accurate at 75.7 degrees. The authors discuss the industry standard and recommended setup angle of 75.5 degrees and question whether it is actually a good benchmark (Young and Wogalter, 2000). Further empirical research was recommended to substantiate this figure and to define the acceptable level of deviation. The bubble level method was most successful at achieving the target angle of 75.5 degrees.

A recent study performed by Simeonov et al. (2013) analyzed setup procedures in a manner similar to Young and Wogalter (2000). Ladder users were tested in a laboratory environment utilizing a 16 ft and 24 ft ladder in extended and retracted positions. Participants were instructed to position the ladders based on a no-instruction method, anthropometric stand–reach method, a bubble level indicator, and with a multimodal indicator that provided feedback of proper setup angle with audible confirmation. Testing results revealed the multimodal method was highly accurate with low variability and was significantly faster than the other setup methods.

Methods

Overview

This study utilized two different methods of testing: human factors experimentation and an engineering analysis that included coefficient of friction measurements. Human factors based testing for Experiment 1 involved human participants performing various combinations of ladder setup tasks. Experiment 2 incorporated the human factors results into an engineering model to evaluate the level of risk of the test participants based on setup angles, loading, and coefficient of friction. Coefficient of friction measurements